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HEART RATE VARIABILITY IN EVALUA- TION OF RECOVERY PHASE OF OPEN CHEST SURGERY

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ABSTRACT

SUDEB SAHA: Heart rate variability in evaluation of recovery phase of open chest surgery.
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Heart rate variability(HRV) is a profound technique to assess autonomic nervous system (ANS). Therefore, HRV is widely used in different applications including recovery monitoring. Open chest surgery is relatively complex and lengthy. Open-chest surgery intrudes anatomy and physiology of the chest and significantly reduces the functions for a few days after the operation.

In those recovery days, it is important to monitor the patient's well beingness as well as autonomic nervous system function. HRV is a promising method for this purpose. The purpose of this study is to use HRV in evaluation of recovery phase of open chest surgery.

The study population was 136 patients with elective heart surgery, pulmonary re-sections surgery, and minor pleuropulmonary surgery. The measurements were conducted one day before the operation and for 1–3 days after the operation during the usual episode of treatment at the hospital. Simultaneous ECG signal was measured for 10 minutes. There were two equally sized subgroups A and B based on the type of given physiotherapy of randomized patients in these three surgery type groups.

RR intervals of each measurement were calculated and by using those RR intervals, HRV parameters were found out for every measurements. Statistical tests were performed finding the significant difference between different measurement days. The significance level (p-value) was 0.05. Statistical comparisons of HRV parameters between one day before surgery and 1-3 days after surgery were performed inside all patients as well as inside different specific patient group. Statistical tests between 1 day and 2-3 days after surgery as well as between 2 and 3 day after surgery were also performed. Statistical comparisons of HRV parameters between control group A and B were also performed inside all patients and inside different specific patient group.

The results showed that there were significant differences in some HRV parameters between one day before and 1-3 days after the operation, especially, heart surgery group had strong significant differences among those days. The study finds no significant difference between intervention subgroups A and B except minor pulmonary surgery patients. The study indicates that some HRV parameters were significantly different due to open chest surgery. However, evaluating recovery phase need longer observation period.

Keywords: heart rate variability, autonomic nervous system, open chest surgery.

The originality of this thesis has been checked using the Turnitin Originality Check service.

PREFACE

I have learned a lot during my master degree study time in Tampere University. I started my study in Tampere University of Technology. However, currently it is merged with other universities and renamed as Tampere University.

First of all, I want to praise my Lord, Ideal Sree Sree Thakur. Then, I want to acknowledge all of my friends and family who stayed beside me throughout this journey.

I want to also acknowledge my thesis supervisor Jari Viik who support and guide me throughout this thesis work. He taught me how to do scientific work and gave me a boost of confidence in believing in my own ideas and research. I want to give thanks to Milla Jauhiainen who did her master thesis work based on same study material what I have been used in my thesis.

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Tampere, 3rd March 2020

SUDEB SAHA

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LIST OF SYMBOLS AND ABBREVIATIONS

ANS	Autonomic Nervous System
AR	Autoregressive
C	Cardiac surgery patients group
CABG	Coronary Artery Bypass Grafting
CNS	Central Nervous System
ECG	Electrocardiogram
FFT	First Fourier Transform
HF	High Frequency
HFP	High Frequency Power
HR	Heart Rate
HRV	Heart Rate Variability
IBI	Inter Beat Interval
ICU	Intensive Care Unit
IMT-P	Inspiratory muscle training physiotherapy
LF	Low Frequency
LFP	Low Frequency Power
Ln	natural logarithm
MI	myocardial infraction
PEP-P	Positive expiratory pressure physiotherapy
PM	Minor pleuropulmonary surgery patients group
PNS	Parasympathetic Nervous System
PR	Pulmonary resection surgery group
PREOP	Preoperative measurement
RSA	Respiratory Sinus Arrhythmia
SNS	Sympathetic Nervous System
ULF	Ultra Low Frequency
VATS	Video-assisted thoracoscopic surgery
VE	Ventricle Ectopic
VLF	Very Low Frequency
1POP	First Postoperative Measurement
2POP	Second Postoperative Measurement
3POP	Third Postoperative Measurement

1. INTRODUCTION

Cardiothoracic Surgery is the surgical treatment which is related with the treatment of diseases affecting organs within thorax, mainly heart and lungs. Since second world war, cardiothoracic surgery rapidly grown surgery. The procedure of this surgery is relatively lengthy and complex. This surgery requires support from advanced forms of technology and intensive therapy for the patients is needed after surgery.[38]

After the surgery, the patient usually spend five to seven days in the hospital. First 24 hours patient stay in intensive care unit, usually with a breathing tube. Anaesthesia will not have worn off, so patient will likely wake up after surgery in the Intensive Care Unit (ICU) room. When patients are able to breathe on their own way then breathing tube is removed. The heart rate, temperature, breathing status, blood pressure, pain level, chest tube drainage and other things are monitored by trained nurses and personals. When the surgery team feels that patients are ready to move in another unit in hospital then patients move to another unit. However, monitoring patients keep going until patients are strong enough to leave the hospital. Recovery in the hospital days may include removing drainage tube, walking in the hallways, daily lab test and chest x-ray. The vital sign, breathing status, glucose and other things are monitored closely in those days.[47]

The measure of variation in Heart Rate (HR) is called Heart Rate Variability (HRV). The heart and Autonomic Nervous System (ANS) altogether control the heart rate of our human body. The Electrocardiogram (ECG) measure the heart signal which contains clearly recognizable QRS complex. The time difference between two conjugative QRS complex is called RR interval which is the main basis of HRV analysis. There are many signal processing and mathematical

methods which are applied to the RR interval signal to obtain different factors affecting the HRV.[22]

The ANS controls mostly HRV and the efferent part of ANS can be divided into two opposing limbs. The sympathetic and parasympathetic nervous system exert opposite action on every most organs including heart. The HR fluctuation can be classified into the influence of sympathetic and parasympathetic nervous system with HRV analysis. With HRV analysis the different factors directly or indirectly affecting ANS can cause abnormal variation in the HR can be studied.

Purpose of this study is to evaluate the recovery phase of thoracic surgery with HRV analysis. HRV analysis might be a novel and useful tool for monitoring the recovery phase of cardiothoracic surgery. It was expected, that HRV parameters are significantly changed and varied from before surgery day to after surgery days. Statistical analyses were also performed in this study.

The study material was collected from Tampere University Hospital, Heart Center, Finland during 2013-2016. The patients were adult thoracic surgery patients with various types of elective cardiac and pulmonary operations. Physiotherapy was provided throughout the episode of care and the ECG signal was measured one day before and for 1-3 days after the surgery. A physiotherapist preformed physiotherapy interventions and all the measurements at the Heart Center. The author processed and prepared that ECG signal for HRV analysis. Visual and statistical analysis were used for analysing the results.

This paper is structured as follows. Chapter 2 discusses the theoretical background of this thesis which were studied doing this thesis work. Chapter 3 discusses the material and methods which were taken performing this thesis work. Chapter 4 presents the results which were got from this work. Chapter 5 dis-

cusses the different important points of this whole thesis work. Chapter 6 summarizes the outcomes and the whole document. References are included in the reference chapter.

2. THEORITICAL BACKGROUND

2.1 The Human Heart

Heart is the core of cardiovascular system of human body which pumps and contracts deoxygenated blood to the lungs and oxygenated blood to the body. There are four chambers in heart: left atrium, left ventricle, right atrium and right ventricle (see Figure 1). Oxygen-poor blood enter into right atrium from the systemic veins, superior vena cava brings oxygen-poor blood from the head and arms and the inferior vena cava brings oxygen-poor blood from the abdomen and legs. Then oxygen-poor blood moves through tricuspid valve to right ventricle. Deoxygenated blood pump out through pulmonic valve to lungs through pulmonary arteries. The blood becomes oxygenated in the lungs and come back to the left atrium through pulmonary veins. Then, this rich-oxygenated blood move to left ventricle through mitral valve and pump out through semilunar valve to systemic arteries and body tissues. This is done regularly and continuously. The heart muscle is doing this pumping and contraction. All the components of intrinsic conduction system contain autorhythmic cardiac cells. These cells initiate and spread action potential throughout the heart.[11]

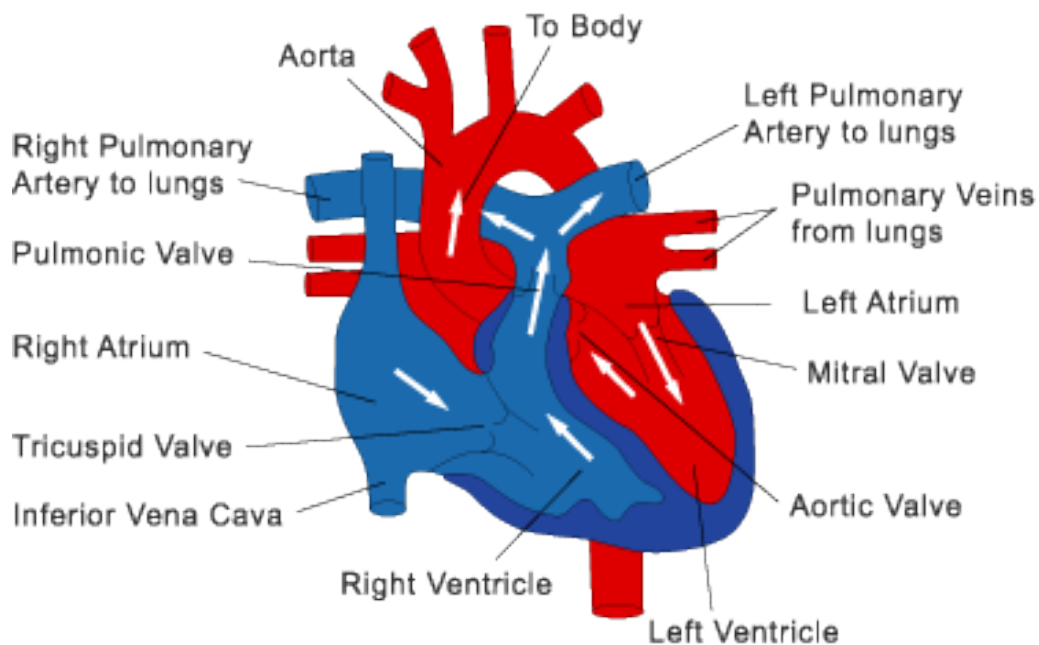


Figure 1. The human heart, Oxygen-poor blood colored as lighter blue and oxygen-rich blood is colored as red. Taken from [3]

2.2 Autonomic Nervous System

The Nervous system carries messages to and from brain and spinal cord to the different parts of our body which is a very complex network of nerves and cells[33]. The nervous system in our body is divided into two different kinds. One is Central Nervous System (CNS) and other one is Peripheral Nervous System (PNS) (see Figure 2). CNS includes brain and spinal cord. PNS includes Autonomic Nervous System (ANS) and Somatic Nervous System (SNS)[15].

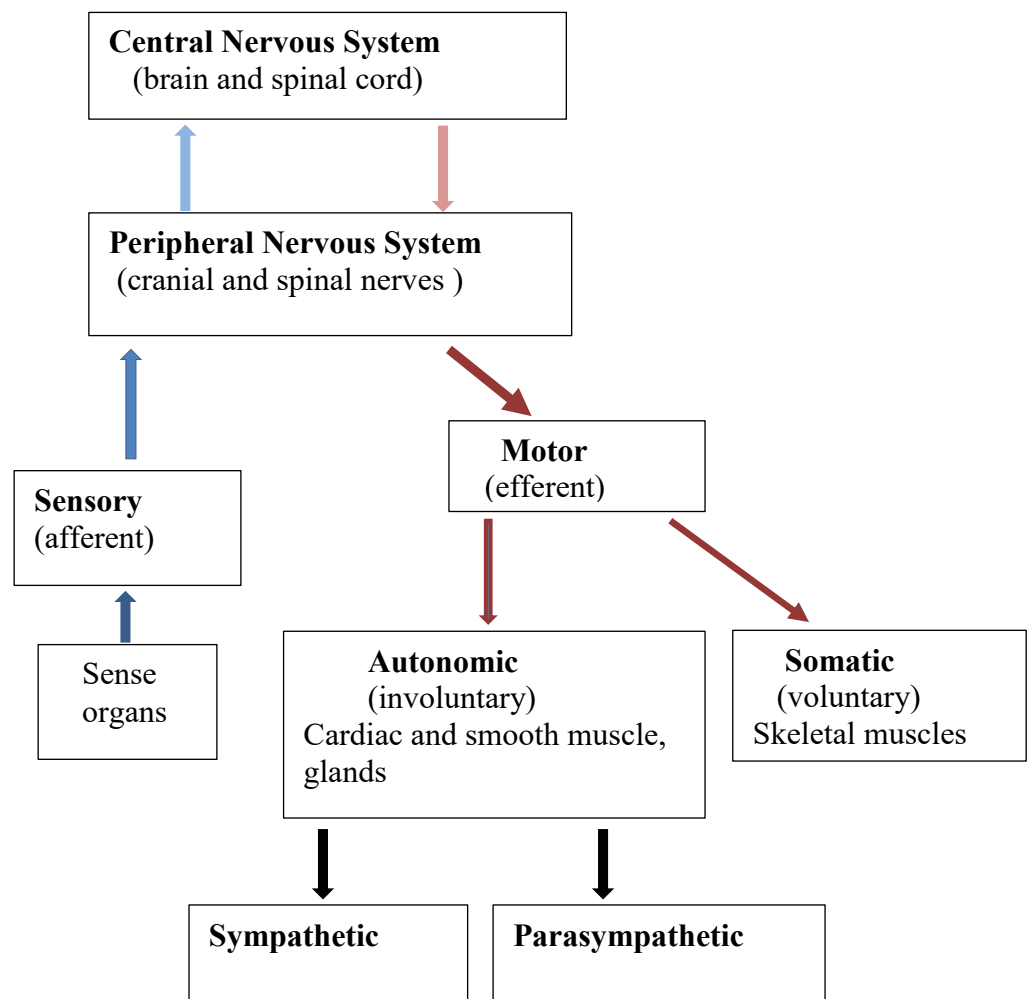


Figure 2. Structural classification of Nervous System. Central nervous system receives input via sensory fibers and it issues commands via motor fibers. The efferent and afferent fibers together form the nerves which constitute the peripheral nervous system. Modified from[28]

Autonomic nervous system is a control system which controls body function automatically. It regulates the nerves of inner organs of our body which are not

controlled consciously. Autonomic nervous system is divided into three different branches. One is sympathetic and other one is parasympathetic and another one is enteric.[33]

Sympathetic nervous system relates with body's flight or fight mood. Parasympathetic relates with body's resting and normal mood. Enteric relates with digestion. In this thesis work, sympathetic and parasympathetic nervous systems are studied. Despite of a few exceptions, body organs which are served by ANS receive fibers from both sympathetic and parasympathetic divisions. As seen in Figure 3, the automaticity of sinus is controlled by two branches of autonomic nervous system. To keep the body system running smoothly, counterbalancing each other activity, sympathetic and parasympathetic divisions serve the same organ but essentially cause opposite effects[28].

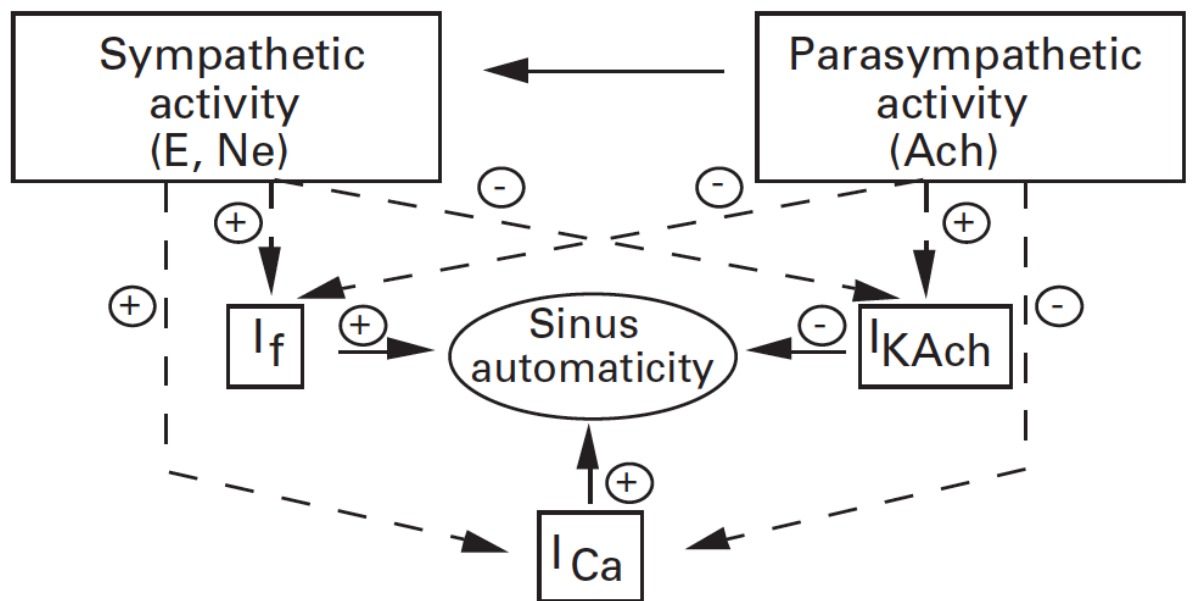


Figure 3. Effect of the autonomic nervous system on the ionic currents and resulting changes of sinus automaticity, E = epinephrine; NE = norepinephrine; Ach = acetylcholine; Ica = calcium current; If = hyperpolarisation-activated “pacemaker” current; IKAch = potassium current . Taken from [44]

2.2.1 Sympathetic Nervous System

Sympathetic Nervous System (SNS) is vastly active when our body is excited by stimulus. SNS regulates flight and fight responses. Basically, it makes us ready for strenuous physical activity. When we face emergency or threatening

situation then SNS prepares the body for that situation. Deep and rapid breathing, fast heartbeat, dilated eye pupils are the sure sign of sympathetic activity. Under those conditions, heart rate, blood pressure and blood glucose levels are increased by SNS that help us to cope with those situations.[29]

SNS division is also called thoracolumbar division because its preganglionic neurons arise from T1 through L2 of the spinal cord (see Figure 4). These preganglionic axons are mostly short and synapse with postganglionic neurons within ganglia of sympathetic ganglion trunk. The sympathetic ganglion trunk or chain lies in parallel along either side of spinal cord. This preganglionic axon may synapse with postganglionic neuron at same level or different level from which it arise. Interestingly, one preganglionic axon can synapse with several postganglionic neurons in many different ganglia.[29]

The long postganglionic axon then extends to the organ it serves. Or the preganglionic axon pass through the sympathetic ganglion chain without synapsing with postganglionic neurons and form part of the splanchnic nerves. The splanchnic nerves travel to viscera for synapsing with postganglionic neurons which found in a collateral ganglion. The collateral ganglion is located in the halfway between CNS and visceral tissue. It is the celiac and the superior and inferior mesenteric ganglia which supply the pelvic and abdominal organs. After leaving these collateral ganglion, postganglionic axon travel to the nearby visceral organ it serves.[28]

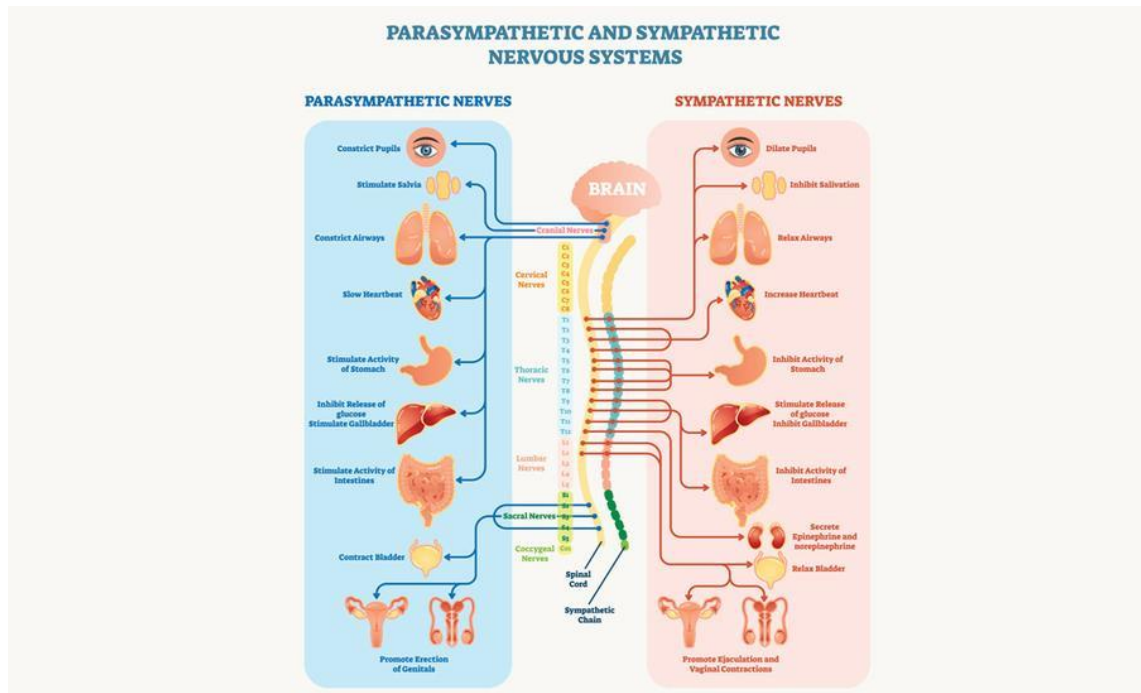


Figure 4. *Anatomy and physiology of the autonomic nervous system. Taken from[28]*

2.2.2 Parasympathetic Nervous System

Parasympathetic nervous system (PNS) works for our rest and peace. Activity of this division mostly is active when our body is not threatened and is at rest. It is also called resting and digesting division. After taking meal when we take rest then it is active and it surely slows down the heart activity. Blood pressure, respiratory and heart rates are at normal levels, digesting food is going by digestive tract[29].

PNS division is also called craniosacral division because the preganglionic neurons arise from the brain nuclei of several cranial nerves- III, VII, IX and X and from S2 through S4 of the spinal cord (see Figure 4). In this division, the axons of preganglionic neurons are longer than preganglionic axons of sympathetic system. These preganglionic axons synapse with postganglionic neurons within terminal ganglion which is closed to or embedded within the organs they serve. The axons of postganglionic neurons are short. Cranial nerves send their axon serving head and neck organs. In a terminal ganglion, preganglionic axon synapse with the ganglionic motor neuron. After synapsing, postganglionic neurons

extends towards effector tissue. The preganglionic neurons which arise from sacral region leave spinal cord and form pelvic splanchnic which travel to the pelvic cavity. They synapse with postganglionic motor neurons in terminal ganglion which is close to or embedded within the organs they serve.[28]

2.2.3 Comparison Between Sympathetic and Parasympathetic

Distinguishing features of these two different parts of ANS are listed in Table 1.

Table 1. *Distinctive characteristics of the sympathetic and parasympathetic system*

Sympathetic System	Parasympathetic system
originates from T1 through L2 of the spinal cord	originates from the brain nuclei of several cranial nerves- iii, VII, IX and X and from S2 through S4 of the spinal cord
ganglia located in collateral ganglion or sympathetic ganglion trunk	terminal ganglion is close to or embedded within target tissue
Ratio of preganglionic fiber to postganglionic fiber is 1:20	1:1 ratio of preganglionic fiber to postganglionic fiber
diffuse discharge of activity is possible at any given moment.	active on specific organ at any given moment
predominant during emergency and exercise	predominant during not threatened and resting condition

Sympathetic and parasympathetic both are the part of ANS but they are working on organs in opposite with respect to each other. The effects of them on different organs are listed in Table 2.

Table 2. *Effects of autonomic nervous system on different organs/systems.*

Organs/Systems	Sympathetic effects	Parasympathetic effects
Eye(iris)	Dilated pupils	Constricted pupils
Eye(ciliary muscle)	Relaxation for distance vision	Contraction for close vision
Heart	HR, rate of conduction and force of contraction increase	HR and rate of conduction decrease
Digestive system	decreasing secretion by digestive system glands; constricted sphincters	Increasing mobility of smooth muscle and secretion by digestive system glands; relaxed sphincters
Liver	Released glucose to blood	No effect
Lungs	Dilated bronchioles	Constricted bronchioles
Kidney	Decreased urine output	No effect
Glands-salivary, lacrimal, gastric	Inhibits	stimulates
Adrenal medulla	Increased secretion of epinephrine, norepinephrine	No effect
Sweat glands of skin	Produced perspiration	No effect
Arrector pili muscle	Produced goose bumps	No effect
Penis	Ejaculation	Erection
Cellular metabolism	Metabolic rate increased	No effect

2.3 Heart Rate Variability

The complex and constantly changing oscillations of heart allow the cardiovascular system to rapidly adjust sudden physical and physiological challenges to homeostasis[40].

The heart is constantly regulated by ANS to meet life's demands, resulting in time variations between each heartbeat. The variation between two consecutive heartbeat is described by HRV. It is universally accepted as a non-invasive marker of operation on the ANS.[8]

It is a predictor of long-term survival after acute myocardial infarction (AMI). Decreased HRV can be an indicator of severe coronary artery disease, heart failure, aging and diabetic neuropathy. Whereas increased HRV is a sign of good functional heart .[18]

The control of HR includes both sympathetic and parasympathetic branches of the ANS. The activity of the SNS increases HR and reduces HRV, while the activity of the PNS decreases HR and increases HRV[1]. Autonomous performance control includes many interconnected areas of the central nervous system, which form the so-called central autonomic network. Arterial baroreceptor reflex as well as respiration are known to cause rapid changes in heart rate in addition to this central control. The baroreflex is based on baroreceptors that are mounted on the walls of some large vessels and can feel the stretching of the walls of the vessels caused by increased pressure. Both sympathetic and parasympathetic activity is affected by the stimulation of baroreceptors via a common baroreflex arc (see Figure 5). Typically, the most conspicuous oscillatory component of HRV is respiratory sinus arrhythmia (RSA), in which the stimulation of the vagus nerve is cut off during inhalation, and therefore HR increases during inhalation and decreases during exhalation. This HRV portion of high frequency (HF) is thus based at respiratory frequency and is considered to range from 0.15 to 0.4 Hz. Another important feature of HRV is the component of low frequency (LF) varying from 0.04 to 0.15 Hz. The HF component is mediated almost exclusively by PNS activity, whereas the LF component is mediated

by SNS and PNS activity as well as by baroreflex activity[1],[6]. However, the origin of the LF oscillations is regarded as dominated by SNS and the normalized power of the LF component could be used to evaluate sympathetic efferent activity[34],[10]. In contrast, the fluctuations below 0.04 Hz were not studied as much as the higher frequencies. These frequencies are usually split into very low frequency (VLF, 0.003-0.04 Hz) and ultra low frequency (ULF, 0-0.003 Hz) bands, but the ULF band is generally omitted in the case of short-term recordings[6]. Such lowest frequency rhythms are descriptive of HRV signals and were related to, for example, humoral influences such as thermoregulatory processes and the renin-angiotensin system[1].

Heart rate variability is a commonly used tool when attempting to evaluate the functioning of autonomic cardiac regulation. It has been used as an indirect instrument for assessing the functioning and equilibrium of the autonomic nervous system (ANS) in multiple studies related to cardiovascular science and various applications of human well-being.[22]

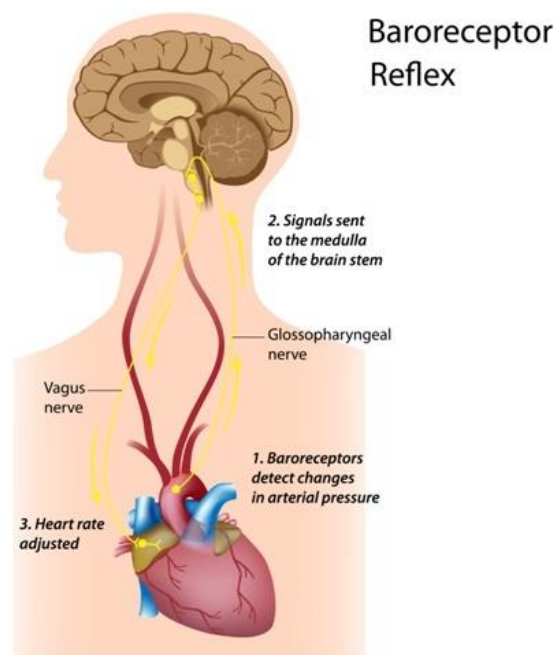


Figure 5. Functioning of the baroreflex arc. Taken from[22]

2.3.1 Problems with HRV Measurement

The detection of HRV changes over a period of hours or days requires the collection and analysis of a large volume of ECG data. Traditionally this has been done with Holter devices that record the ECG in outpatients over periods of 24 h to several weeks. Due to the relative infrequency of such events, data capture on dynamic changes in HRV in the timeframe before arrhythmias or ischaemic events is more difficult to attain. Signal quality and elimination of background ‘noise’ when analyzing HRV is critical. It is particularly difficult to interpret HRV in patients who are not in the rhythm of the sinus (e.g. atrial fibrillation) or those with highly irregular HR or numerous ventricle ectopic (VE) beats. Most HRV studies exclude patients who are not in the rhythm of the sinus but there is controversy about multiple VEs. Some authors support the exclusion of signals containing more than 10 ectopic beats per hour[19].

If evaluating a signal with ectopic beats, most writers suggest eliminating and correcting the ectopic beats for them by changing the R wave peak position and putting a beat between the two adjacent beats at midway. A final problem when calculating HRV is to locate the consecutive R-wave peaks on the ECG with accuracy. That needs a robust algorithm for the R-wave detector. The more precise the R-wave detector, the less error in the HRV spectrum analyzed. A totally skipped R wave can cause more error than a marginally mis-corrected R wave, and this error is more expressed in the high frequency power (HFP) than low frequency power (LFP) in the HRV spectrum.[37]

2.3.2 QRS Detection and Beat Detection

The purpose of the study of heart rate variability is to analyze the rhythm of the sinus modulated by the autonomic nervous system. Therefore, the occurrence times of the SA-node action potentials should be technically detected which initiate each heartbeat. However this is not feasible in practical applications. Alternatively, an electrocardiogram (ECG) is registered by placing two or more electrodes on skin contact, and the ECG measures heart beats. The P-wave arising from atrial depolarization is the nearest detectable phenomenon in the ECG as opposed to SA-node firing (see Figure 6). Nevertheless, the P-wave’s signal-to-noise ratio is clearly lower than that of the strong QRS complex which primarily

results from ventricular depolarization. Therefore, the duration of heart beat is generally measured as the time difference between the easily detectable QRS complexes. A typical QRS detector is a preprocessing component which is followed by a decision rule. In recent decades numerous QRS detectors have been proposed[48],[9],[12],[35].

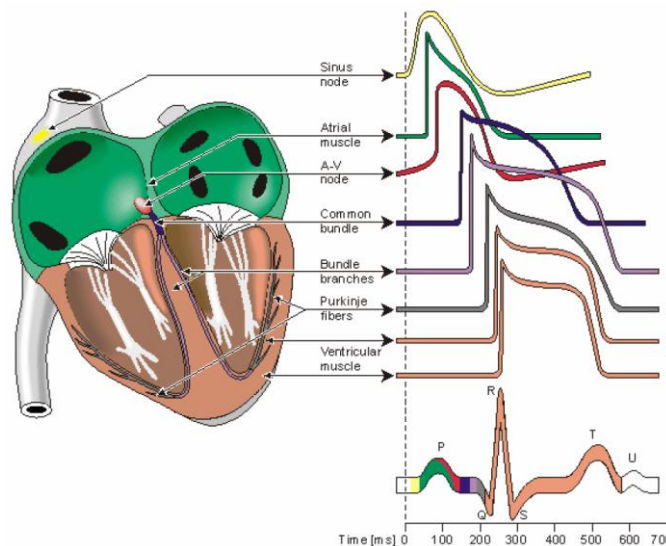


Figure 6. Cardiac electrophysiology. Taken from[22]

2.3.3 Measurement Principle And Analysis Methods of HRV

Variation has long been known in the time interval between consecutive R wave peaks of the QRS complex. Measurement of this RR interval is used to determine variation in heart rate[17].

HRV is measurable in time or in frequency domains. Methods in the time domain are the easiest to execute. In the ECG trace, each N (or R) point is defined, and variables such as mean HR and measured the longest and shortest N-N intervals. Analysis of the time domain is a general measure of the autonomous nervous system balance and is based on altered versions of the standard heart rate deviation calculation, defined in terms of the R-R sinus intervals over time. Frequency domain analysis uses either autoregressive (AR) or fast Fourier transform (FFT) techniques to delineate parasympathetic (high-frequency

components) from sympathetic (low-frequency components) of autonomic control. These measure how the ECG signal variance (or power) changes as a frequency function.[37],[4]

Considering the complex heart control systems it is reasonable to assume that the heart rate regulation involves nonlinear mechanisms. Analyzing the nonlinear properties of HRV, the Poincaré plot, recurrence plot, approximate and sample entropy are measured commonly. The number of studies using such methods has substantially increased in the last few years. However, the downside of those methods is still the difficulty of the results being interpreted physiologically.[22]

2.3.4 Heart Rate Variability Parameters

There are a lot more parameters for HRV. Many of them, however, are redundant. There are six widely used time domain measurements: SDANN, 24-hr SD, SD, RMSSD, RR50, and % RR50[4]. HRV time-domain parameters calculate the sum of interbeat interval (IBI) measurement variability which is the period between successive heartbeats (see Table 3). These values can be expressed in the original units or as the natural logarithm (Ln) of the original units to obtain a more normal distribution[45].

Table 3. HRV time domain parameters. Modified from[40]

Parameter	Unit	Description
SDNN	ms	Standard deviation of NN intervals
SDRR	ms	Standard deviation of RR intervals
SDANN	ms	Standard deviation of the average NN intervals for each 5 min segment of a 24 h HRV recording
SDNN index (SDNNI)	ms	Mean of the standard deviations of all the NN intervals for each 5 min

		segment of a 24 h HRV recording
pNN50	%	Percentage of successive RR intervals that differ by more than 50 ms
HR Max – HR Min	bpm	Average difference between the highest and lowest heart rates during each respiratory cycle
RMSSD	ms	Root mean square of successive RR interval differences
HRV triangular index		Integral of the density of the RR interval histogram divided by its height
TINN	ms	Baseline width of the RR interval histogram

Measurements of the Frequency Domain estimate the distribution of absolute or relative power into four frequency bands. The Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1996) divided heart rate (HR) oscillations into ultra-low-frequency (ULF), very-low-frequency (VLF), low-frequency (LF), and high-frequency (HF) bands (see Table 4).

Table 4. *HRV frequency domain parameters. Modified from[40]*

Parameter	Unit	Description
ULF power	ms ²	Absolute power of the ultra-low-frequency band (≤ 0.003 Hz)
VLF power	ms ²	Absolute power of the very-low-frequency band (0.0033–0.04 Hz)
LF peak	Hz	Peak frequency of the low-frequency band (0.04–0.15 Hz)
LF power	ms ²	Absolute power of the low-frequency band (0.04–0.15 Hz)
LF power	nu	Relative power of the low-frequency band (0.04–0.15 Hz) in normal units
LF power	%	Relative power of the low-frequency band (0.04–0.15 Hz)
HF peak	Hz	Peak frequency of the high-frequency band (0.15–0.4 Hz)
HF power	ms ²	Absolute power of the high-frequency band (0.15–0.4 Hz)
HF power	nu	Relative power of the high-frequency band (0.15–0.4 Hz) in normal units

HF power	%	Relative power of the high-frequency band (0.15–0.4 Hz)
LF/HF	%	Ratio of LF-to-HF power

Power is the energy of a signal found within a frequency band. Measurements of frequency-domains can be expressed in absolute or relative power. Absolute power is measured as ms squared divided by cycles (ms²/Hz) per second. Relative power is estimated as the percentage of total HRV power or in normal units (nu), dividing the absolute power for a specific frequency band by the sum of the absolute power of the LF and HF bands. This allows us to compare two customers ' frequency-domain measurements directly, despite wide variation in specific band power and total power among healthy, age-matched people.[24] The ULF band (average 0.003 Hz) indexes IBI variations between 5 min and 24 h and is measured using 24 h recordings[20].

The VLF band (0.0033–0.04 Hz) contains rhythms with intervals varying from 25 to 300 s. The LF band (0.04–0.15 Hz) consists of rhythms with periods between 7 and 25 s and is affected by ~3 to 9 bpm respiration. Within a sample of 5 min, there are 12–45 complete periods of oscillation[24]. Breathing from 9 to 24 bpm influences the HF or respiratory band (0.15–0.40 Hz)[14]. Under controlled conditions, the ratio of LF to HF power (LF / HF ratio) can estimate the relationship between sympathetic nervous system (SNS) activity and parasympathetic nervous system (PNS). Total power is the sum of energy in the ULF, VLF, LF, and HF bands for 24 hours and in the VLF, LF, and HF bands for short-term recording[41].

Non linear measurements allow us to quantify the unpredictability of a time series[43].

Table 5. *Non linear HRV parameters. Modified from[40]*

Parameter	Unit	Description
S	ms	Area of the ellipse which represents total HRV
SD1	ms	Poincaré plot standard deviation perpendicular the line of identity
SD2	ms	Poincaré plot standard deviation along the line of identity
SD1/SD2	%	Ratio of SD1-to-SD2
ApEn		Approximate entropy, which measures the regularity and complexity of a time series
SampEn		Sample entropy, which measures the regularity and complexity of a time series
DFA α_1		Detrended fluctuation analysis, which describes short-term fluctuations
DFA α_2		Detrended fluctuation analysis, which describes long-term fluctuations
D2		Correlation dimension, which estimates the minimum number of variables required to construct a model of system dynamics

PNS activity or vagal stimulation which decrease the HR or increase the mean RR interval and increase HRV. The HF component of HRV is mainly based on the efferent vagal stimulation. The root mean square of successive RR interval (RMSSD) reflects the higher frequency fluctuation of HRV.[46]

SNS activity which increase HR or decrease mean RR interval and decrease HRV. The LF component of HRV is considered to both parasympathetic and sympathetic activities. However, probably sympathetic activity is more dominant component. HF power normalised unit (n.u) has a direct link to parasympathetic activity and LF power normalised unit (n.u) has a direct link to sympathetic activity. In Kubios HRV, PNS index is computed based on mean RR, RMSSD and HF power (n.u.). SNS index is computed based on mean HR, Baevsky's stress index and LF power (n.u.). The values of these parameters are compared to their normal values and computed as mean deviation from their normal values. In summary, PNS and SNS indexes give reliable estimates of parasympathetic and sympathetic activities of ANS as compared to normal resting values.[46]

2.4 HRV is More Than The ANS

HRV was also known to be a surrogate parameter of the complex brain-cardio-vascular relationship. According some newer theories, HRV reflects as much the state of the heart as the state of the brain. The neurovisceral integration model suggests that the cardiac vagal tone, defined as HF-index in HRV among others, may mirror the functional balance of the neural networks involved in interactions between emotion and cognition.

The sinoatrial node, respiratory system, endocrinological system, immunological system, metabolic function and some other physiological systems with Influence on HRV can be reflected by HRV. HRV is more than an indicator of ANS and it has some significances on some other physiological systems.[7]

2.5 Effect of Open Chest Surgery to HRV

Lung surgery has in the past included a big open operation, known as thoracotomy. This approach involves making a large incision and spreading the ribs apart with retractors, in order to gain access to the lungs. With new technological advances, lung surgery can now be done via a less invasive technique, called "Minimally Invasive Pulmonary Resection"[13].

There are several risk scores for mortality in cardiac surgery. All of these include a significant number of independent risk factors. The operative mortality in elective cardiac surgery patients is small, the number of events reported per year is limited, and the risk model may be overfitted[36]. Autonomic function after myocardial infarction has been shown to be a strong predictor of cardiac mortality[25]. Currently, HRV is primarily used in routine clinical practice for risk stratification of occurrence of malignant arrhythmia, and sudden death in patients with myocardial infarction (MI)[30]. Previous studies showed that HRV decreases significantly after coronary artery bypass grafting (CABG), even more distinctly than in patients with MI[23]. In addition, in clinical practice a large number of patients with an implanted artificial valve were found to have decreased HRV in the first few months following cardiac valve surgery[31].

In relevant literature there are practically no significant studies which analyzed HRV after cardiothoracic surgery. Therefore, the purpose of this study is that the understanding of recovery phase through HRV immediately after cardiothoracic surgery.

3. MATERIALS AND METHODS

The patient's ECG signals were measured at Tampere University Hospital, Finland. The patients were mainly divided into two types of surgery patients. Thoracic surgery includes cardiac surgery and pulmonary surgery, these two types of patient's ECG data was extracted by the author. The patients have different histories and conditions, therefore some basic medical information of patients are discussed. The author measured the RR intervals for those ECG signals. Those RR intervals were used to measure the HRV parameters of those patients. The statistical analysis was performed by the author for evaluation of recovery phase of those patients.

3.1 Materials

Between May and June 2013, a pilot study consisted of 12 patients was measured. The study's second phase began in September 2013 and concluded in Spring 2016. The hospital recruited a total of 136 patients from elective scheduled cardiothoracic surgery. The patient's participation was voluntary and focused on informed consent. The institutional ethics committee of the Pirkanmaa Hospital District, Finland approved the study.

The author only analysed the ECG signal. The descriptive characteristics of patients are presented from Milla Jauhiainen's master of science thesis[16] in Table 6.

Table 6. *Descriptive characteristics of patients and some of the measurements were not measured due to some complications.*

Variable	Value(Mean \pm SD)	Study Population(N)
Age (Years)	63.4 \pm 12.8	136
Gender(male/female)	84/52	136
Weight (Kg)	81.0 \pm 16.8	132
Smoking	25	136

The study population's age was varied from 18 to 79 years. There were three different groups based on their surgery type. Cardiac surgery patients (C), minor pulmonary surgery patients (PM) and pulmonary surgery patients with resection (PR) were these three groups. Different types of open heart surgeries were included in group C. A surgical biopsy was performed in PM and PM surgery was done by using either video-assisted thoracoscopic surgery (VARTS) or thoracotomy. In PR, the complete lung or a portion of lung was removed and PR surgery also was done by either VARTS or thoracotomy.

Two equally sized intervention groups were created by randomizing patients from these three surgery. These intervention groups were created based on the physiotherapy they got. Positive expiratory pressure physiotherapy (PEP-P) for control group (A) and inspiratory muscle training physiotherapy (IMT-P) for control group (B). Whereas every other physiotherapies were same for them.

All those physiotherapies and measurements were done amongst normal hospital routines of the patient. Due to the study, the processing of care and nursing were not affected or prolonged. The measurements were performed one day before the surgery (PREOP) and 1-3 days after the surgery (1POP, 2POP and 3POP respectively). 3POP was measured only in surgery group C.

3.2 Measurement Procedure

The measurements usually were done in one session but some of them were done in two separate sessions. The measurements were measured by a physiotherapist along with other routines of hospital. The procedure of measurements were same for before operation and for 1-3 days after the operation. However, the execution of procedure was effected by patient's condition after surgery.

In PREOP, after the measurement, physiotherapy with PEP-P and IMT-P was given to evaluate the patients' true baseline before any respiratory training. Physiotherapy was provided in postoperative measurements before the measurement. The measurement procedure is clearly described in Milla Jauhiainen's master's thesis[16].

3.3 Measurement Devices

ECG was measured by a portable device (see Figure 7). The device was similar one that described by Vuorela et al.[49]. 256 Hz was the sampling frequency of ECG. Two electrodes were used to measure the ECG. At the height of fifth intercostal space, two electrodes were placed in the midaxillary line and other two electrodes are placed in the opposite to the first two electrodes. Firstly, data was stored in the device memory and then after each measurement it was transferred to a computer.

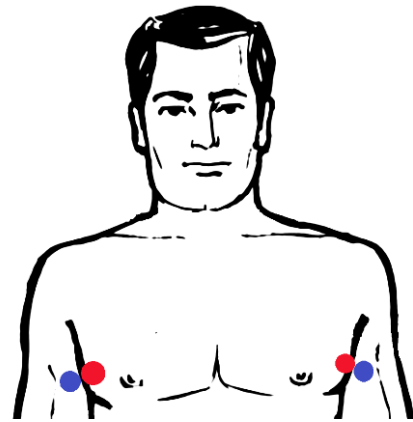


Figure 7. Device is for impedance pneumography, measuring bioimpedance and ECG simultaneously (left) and tetrapolar electrode configuration (right). Four commonly used electrodes are attached to the skin. Blue electrodes are used for driving a small alternating current to the body and red electrodes measure the resulting voltage. Sketch on the right modified from[16]

Two available devices were used to collect data. One device of the two available devices measured ECG data. Two devices were similar but the AD transducer's reading might vary between devices. One is used for the patients throughout the measurement if it works properly otherwise other device was used.

3.4 Signal Processing

The ECG signal was processed with MATLAB R2015b software. The R peaks were detected by using detection algorithm of Sergey Chernenko[26]. The signal processing flow for measuring RR interval is presented in Figure 8.

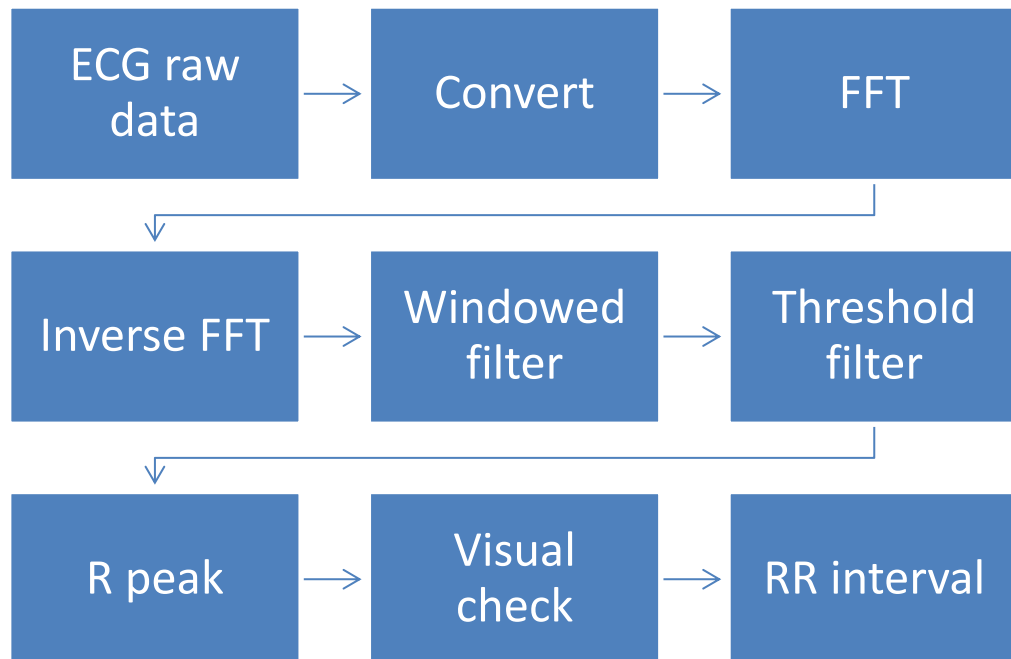


Figure 8. ECG signal processing scheme for measuring RR interval.

The main task of ECG signal processing was RR interval calculation. The 10 minutes ECG raw signal was selected for measuring RR interval. The 10 minutes was selected based on the restful state of patients. The start and end indices of ECG signal were selected by Milla Jauhiainen[16]. The signal processing for detecting R peaks is illustrated in Figure 9. As the ECG is uneven. So the first step was to straighten ECG signal. To do that, direct fast Fourier transform-FFT was used removing low frequencies. Then, inverse FFT was used for restoring ECG. After that, windowed filter was used to find local maxima. Windowed filter took only maximum values in its window and ignores all other values. Window of default size was used in this step. For removing small values and taking only significant ones, a threshold filter was used. For getting

all the peaks, window size adjusted and repeated filtering. Then visually checked the results. A few measurements did not need repeated filtering.

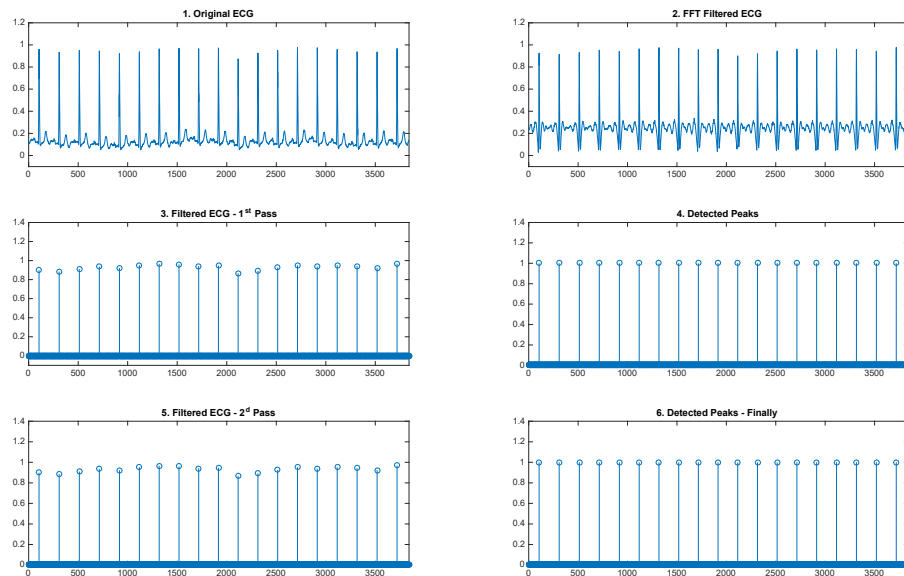


Figure 9. MATLAB figures of Signal processing steps of a random measurement for detecting R peaks. The first 15 seconds of 10 minutes measurement is taken for showing the steps clearly.

The calculated RR intervals were in millisecond. The RR intervals were saved as a text file for each measurement. These text files were used as input in software Kubios.

3.5 Kubios HRV Parameters

The RR intervals were used as input in Kubios HRV standard 3.1.0. Software kubios HRV standard analysed RR intervals and gave HRV parameters of respective measurement. Kubios HRV standard was used as an extractor of the HRV parameters for each measurement. The PNS index is computed from Mean RR (ms), RMSSD (ms) and SD1 (%); and SNS index is from Mean HR (bpm), Baevsky's stress index and SD2 (%)[22]. All parameters with unit and description is presented in Table 7.

Table 7. Summary of the HRV parameters from the HRV Analysis Software Kubios with descriptions. Taken from[22]

PARAMETER	UNIT	DESCRIPTION
Overview		
PNS index	–	Parasympathetic nervous system activity compared to normal resting values
SNS index	–	Sympathetic nervous system activity compared to normal resting values
HR zones	[%]	Time spent in Maximum, Hard, Moderate, Light, Very light, and Inactive HR zones
Stress zones	[%]	Time spent in Very high, High, Elevated, Normal, and Low stress levels
RMSSD zones	[%]	Time spent in Very low, Low, Lowered, Normal, and High RMSSD levels
Energy exp.	[kcal/min]	Energy expenditure is divided into Basal Metabolic Rate (BMR) and activity related energy expenditure. BMR is estimated with Mifflin-St Jeor formula and energy expenditure (EE) using Keytel's model
TRIMP	[TRIMP/min]	Training impulse (TRIMP) is estimated using the exponential Banister's model
Time Domain		
\overline{RR}	[ms]	The mean of RR intervals

STD RR (SDNN)	[ms]	Standard deviation of RR intervals
\overline{HR}	[beats/min]	The mean heart rate
Min & Max HR	[beats/min]	Minimum and maximum HR computed using N beat moving average (default value: N=5)
RMSSD	[ms]	Square root of the mean squared differences between successive RR intervals
NNxx	[beats]	Number of successive RR interval pairs that differ more than xx ms (default value: xx=50)
pNNxx	[%]	NNxx divided by the total number of RR intervals
HRV triangular index	–	The integral of the RR interval histogram divided by the height of the histogram
TINN	[ms]	Baseline width of the RR interval histogram
Stress index	–	Square root of Baevsky's stress index
SDANN	[ms]	Standard deviation of the averages of RR intervals in 5-min segments
SDNNI	[ms]	Mean of the standard deviations of RR intervals in 5-min segments
Frequency-Domain		
Spectrum		Welch's (or Lomb-Scargle) periodogram and AR spectrum estimates
Peak frequency	[Hz]	VLF, LF, and HF band peak frequencies
Absolute power	[ms ²]	Absolute powers of VLF, LF, and HF bands
Absolute power	[log]	Natural logarithm transformed values of absolute powers of VLF, LF, and HF bands
Relative power	[%]	Relative powers of VLF, LF, and HF bands: VLF [%] = VLF [ms ²] / total power [ms ²] x 100% LF [%] = LF [ms ²] / total power [ms ²] x 100% HF [%] = HF [ms ²] / total power [ms ²] x 100%
Normalized power	[n.u.]	Powers of LF and HF bands in normalised units: LF [n.u.] = LF [ms ²] / (total power [ms ²] – VLF [ms ²]) x

		100% $\text{HF [n.u.] = HF [ms}^2\text{]} / (\text{total power [ms}^2\text{]} - \text{VLF [ms}^2\text{]}) \times 100\%$
LF/HF	–	Ratio between LF and HF band powers
EDR	[Hz]	ECG derived respiration (available only if ECG data is used for HRV analysis)
Nonlinear		
SD1	[ms]	In Poincaré plot, the standard deviation perpendicular to the line-of-identity
SD2	[ms]	In Poincaré plot, the standard deviation along the line-of-identity
SD2/SD1	–	Ratio between SD2 and SD1
ApEn	–	Approximate entropy
SampEn	–	Sample entropy
DFA, α_1	–	In detrended fluctuation analysis, short term fluctuation slope
DFA, α_2	–	In detrended fluctuation analysis, long term fluctuation slope
D ₂	–	Correlation dimension
RPA		Recurrence plot analysis
Lmean	[beats]	Mean line length
Lmax	[beats]	Maximum line length
REC	[%]	Recurrence rate
DET	[%]	Determinism
ShanEn	–	Shannon entropy
MSE	–	Multiscale entropy for scale factor values $\tau=1,2,\dots,20$

3.6 Statistical Analysis of HRV Parameters

The HRV parameters were statistically analysed by software environment R. The normality of each HRV parameter out of 53 HRV parameters for PREOP, 1POP, 2POP and 3POP measurement was checked by using Shapiro-Wilk test. Student's paired t-test (or sometimes called Student's dependent t-

test) was used for normally distributed data. Wilcoxon signed-rank test was used for non-normally distributed data. The student's paired t-test and Wilcoxon signed-rank test were performed among in all groups of patients. Those tests were also performed among in patients group PM, PR and C. Those tests compared each HRV parameter of PREOP measurement with the same each HRV parameter of 1POP, 2POP and 3POP measurement respectively. Those tests also compared HRV parameters of 1POP measurement with HRV parameters of 2POP and 3POP measurement. The comparison of HRV parameters between 2POP and 3POP measurement was also performed. In the patient groups, comparison of HRV parameters of 2POP and 3POP measurement was done only for C group.

Student unpaired t-test and Wilcoxon sum rank test were performed in between control group A and B of all surgery groups. These tests were also performed inside the individual patient surgery group. Firstly, the difference of every HRV parameters between two measurement days of one intervention group were measured and then the difference between two measurement days of every HRV parameters of other intervention group were measured and finally performed these statistical tests between two intervention groups with difference of same measurement days. Example, The statistical tests were performed between difference of PREOP and 1POP of intervention group A and difference of PREOP and 1POP. Of course, before performing statistical test the normality of each difference was checked.

The p values of those tests presented with corresponding mean \pm SD values for some specific HRV parameters. PNS and SNS indexes provide reliable estimates of autonomic nervous system activities. The selected HRV parameters for presenting results are PNS index, SNS index, STD RR, RMSSD, Alpha 1, LF [n.u.] and HF [n.u.]. However, all HRV parameters are presented in appendix.

4. RESULTS

4.1 Measurement Results of RR Interval

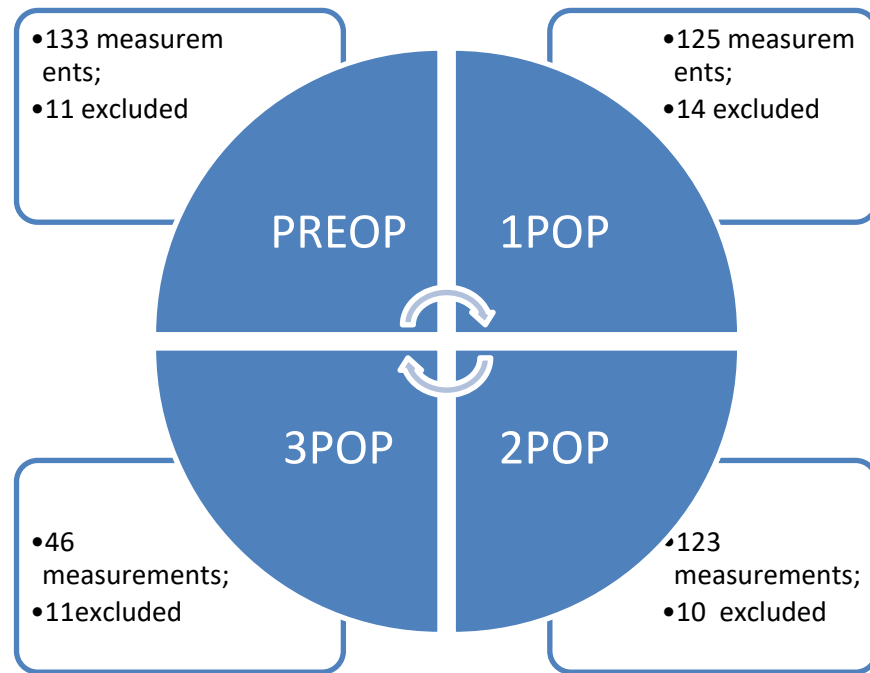


Figure 10. Chart of included and excluded measurements of the patients in the signal processing.

If the QRS detection algorithm detected 95% of R-peaks then RR interval was measured. If it was less than 95% then the measurement was excluded from study. Only the measurements with 95% R-peaks detection were included for measuring RR interval.

In total of 136 patient's ECG signal were planned to analysis but 3 of them were missing due to unsuccessful measurement. Another 3 patients had no post-operative measurement. Some of them did not have 1POP measurements. Some of them did not have 2POP and only heart surgery group (C) had 3POP measurement. Due to unsuccessful (95%) R-peak detection, some measurements were excluded from study (see Figure 10).

4.2 Statistical Tests for All Surgery Group

Table 8. PNS index, SNS index, STD RR, RMSSD, Alpha 1, LF [n.u.] and HF [n.u.] are presented as mean \pm SD for all surgery group on comparison between different measurement days. Student paired t-test for normally distributed data and Wilcoxon signed rank test for not normally distributed data between different measurement days of all surgery groups.

Parameter	Comparison	Mean \pm SD		p value
PNS index	PREOP vs 1POP	0.69 \pm 2.43	0.42 \pm 2.34	0.2418
	PREOP vs 2POP	0.76 \pm 2.69	0.27 \pm 2.35	0.0258
	PREOP vs 3POP	1.54 \pm 3.3	0.85 \pm 2.59	0.1477
	1POP vs 2POP	0.32 \pm 2.15	0.2 \pm 2.32	0.5773
	1POP vs 3POP	0.71 \pm 2.67	0.83 \pm 2.68	0.7816
	2POP vs 3POP	0.62 \pm 2.02	0.68 \pm 2.24	0.8242
SNS index	PREOP vs 1POP	0.46 \pm 1.75	1.12 \pm 2.32	0.0083
	PREOP vs 2POP	0.43 \pm 1.73	1.44 \pm 2.37	0.00001
	PREOP vs 3POP	0.12 \pm 1.84	1.11 \pm 2.27	0.0224
	1POP vs 2POP	1.17 \pm 2.34	1.55 \pm 2.4	0.1188
	1POP vs 3POP	1.18 \pm 2.7	1.22 \pm 2.41	0.9396
	2POP vs 3POP	1.07 \pm 2.34	1.11 \pm 2.27	0.9108
STD RR	PREOP vs 1POP	48.51 \pm 49.45	38.9 \pm 44.44	0.0236
	PREOP vs 2POP	49.65 \pm 53.9	40.79 \pm 47.96	0.0600
	PREOP vs 3POP	64.67 \pm 69.54	56.7 \pm 53.67	0.4125
	1POP vs 2POP	36.46 \pm 40.23	39.77 \pm 47.57	0.4643
	1POP vs 3POP	42.79 \pm 48.88	55.23 \pm 55.21	0.1767
	2POP vs 3POP	43.72 \pm 42.66	53.34 \pm 49.92	0.2724
RMSSD	PREOP vs 1POP	63.12 \pm 75.75	53.68 \pm 71	0.1419
	PREOP vs 2POP	64.88 \pm 83.84	54.95 \pm 72.9	0.1492
	PREOP vs 3POP	87.21 \pm 107.95	80.75 \pm 79.05	0.6603
	1POP vs 2POP	49.84 \pm 65.11	53.3 \pm 71.9	0.6245
	1POP vs 3POP	63.18 \pm 80.53	78.33 \pm 81	0.3039
	2POP vs 3POP	62.95 \pm 65.68	75.15 \pm 71.15	0.2752
Alpha 1	PREOP vs 1POP	0.89 \pm 0.32	0.78 \pm 0.34	0.0023
	PREOP vs 2POP	0.88 \pm 0.32	0.85 \pm 0.38	0.3386
	PREOP vs 3POP	0.82 \pm 0.29	0.68 \pm 0.28	0.0341
	1POP vs 2POP	0.79 \pm 0.34	0.85 \pm 0.39	0.0754
	1POP vs 3POP	0.69 \pm 0.37	0.69 \pm 0.3	0.8148
	2POP vs 3POP	0.7 \pm 0.37	0.67 \pm 0.27	0.9615
LF [n.u.]	PREOP vs 1POP	50.87 \pm 22	45.67 \pm 24.08	0.0309
	PREOP vs 2POP	51.14 \pm 21.22	45.81 \pm 25.02	0.0177
	PREOP vs 3POP	46.94 \pm 20.75	40.79 \pm 20.36	0.1535
	1POP vs 2POP	45.98 \pm 24.22	46.49 \pm 25.16	0.8376
	1POP vs 3POP	41.09 \pm 26.03	40.77 \pm 21.58	0.9587
	2POP vs 3POP	31.8 \pm 22.74	41.05 \pm 20.71	0.0090
HF [n.u.]	PREOP vs 1POP	48.92 \pm 21.86	54.04 \pm 23.88	0.0313
	PREOP vs 2POP	48.66 \pm 21.09	53.88 \pm 24.82	0.0185

	PREOP vs 3POP	52.85±20.63	58.81±20.15	0.1584
	1POP vs 2POP	53.74±24.03	53.2±24.96	0.8293
	1POP vs 3POP	58.57±25.81	58.86±21.37	0.9617
	2POP vs 3POP	67.72±22.51	58.56±20.5	0.0089

*PREOP = preoperative, 1POP = 1. postoperative, 2POP = 2. Postoperative, 3POP = 3. post-operative measurement

The student paired t-test or Wilcoxon signed rank test shows (see Table 8) that there was significant difference in the selected parameters between PREOP and 1POP except PNS index and RMSSD. For SNS index, The statistical test shows that there was significant difference between PREOP and 1-3 post-operative measurement days. The significant level (p-value) was less than 0.05.

4.3 Statistical Tests in Different Surgery Group

4.3.1 Statistical Tests for Surgery Group C

Table 9. PNS index, SNS index, STD RR, RMSSD, Alpha 1, LF [n.u.] and HF [n.u.] are presented as mean \pm SD for surgery group C on comparison between different measurement days. Student paired t-test for normally distributed data and Wilcoxon signed rank test for not normally distributed data between different measurement days of surgery group C.

Parameter	Comparison	Mean \pm SD		p value
PNS index	PREOP vs 1POP	1.92 \pm 3.19	0.67 \pm 2.63	0.0356
	PREOP vs 2POP	2.17 \pm 3.64	0.8 \pm 2.79	0.0185
	PREOP vs 3POP	1.8 \pm 3.32	0.79 \pm 2.65	0.0347
	1POP vs 2POP	0.45 \pm 2.15	0.64 \pm 2.72	0.9197
	1POP vs 3POP	0.67 \pm 2.79	0.75 \pm 2.75	0.8633
	2POP vs 3POP	0.53 \pm 2.07	0.6 \pm 2.27	0.9019
SNS index	PREOP vs 1POP	-0.16 \pm 1.82	1.16 \pm 2.61	0.0226
	PREOP vs 2POP	-0.18 \pm 1.84	1.1 \pm 2.44	0.0099
	PREOP vs 3POP	-0.08 \pm 1.78	1.23 \pm 2.32	0.0029
	1POP vs 2POP	1.32 \pm 2.65	1.22 \pm 2.52	0.8417
	1POP vs 3POP	1.38 \pm 2.77	1.38 \pm 2.48	0.9962
	2POP vs 3POP	1.14 \pm 2.45	1.25 \pm 2.33	0.739
STD RR	PREOP vs 1POP	70.72 \pm 69.37	43.05 \pm 48.43	0.0214
	PREOP vs 2POP	76.53 \pm 77.9	48.42 \pm 55.72	0.0303
	PREOP vs 3POP	69.72 \pm 70.69	56.08 \pm 54.17	0.1626
	1POP vs 2POP	38.99 \pm 37.53	44.31 \pm 52.83	0.6491
	1POP vs 3POP	42.93 \pm 51.43	54.28 \pm 55.96	0.2536
	2POP vs 3POP	41.88 \pm 42.08	52.26 \pm 50.03	0.2069
RMSSD	PREOP vs 1POP	97.15 \pm 105.63	63.9 \pm 79.18	0.0627
	PREOP vs 2POP	105.59 \pm 120.91	70.97 \pm 89.51	0.079
	PREOP vs 3POP	94.15 \pm 110.46	79.65 \pm 80.02	0.3317
	1POP vs 2POP	57.84 \pm 65.69	65.06 \pm 85.36	0.7147
	1POP vs 3POP	63.63 \pm 84.32	76.71 \pm 82.34	0.4196
	2POP vs 3POP	59.99 \pm 64.87	73.3 \pm 71.33	0.2757
Alpha 1	PREOP vs 1POP	0.79 \pm 0.31	0.7 \pm 0.35	0.2899
	PREOP vs 2POP	0.78 \pm 0.32	0.7 \pm 0.37	0.4319
	PREOP vs 3POP	0.81 \pm 0.3	0.7 \pm 0.28	0.1064
	1POP vs 2POP	0.72 \pm 0.35	0.7 \pm 0.38	0.438
	1POP vs 3POP	0.7 \pm 0.38	0.71 \pm 0.31	0.7265
	2POP vs 3POP	0.72 \pm 0.39	0.69 \pm 0.27	0.9911
LF [n.u.]	PREOP vs 1POP	44.64 \pm 21.63	42.25 \pm 24.54	0.6219
	PREOP vs 2POP	44.92 \pm 21.55	33.75 \pm 23.77	0.0358
	PREOP vs 3POP	46.95 \pm 21.34	42.01 \pm 20.85	0.2699
	1POP vs 2POP	43.28 \pm 25.16	34.87 \pm 24.06	0.1782
	1POP vs 3POP	42.65 \pm 26.46	42.26 \pm 22.29	0.671

	2POP vs 3POP	32.67±23.59	42.46±21.28	0.0156
HF [n.u.]	PREOP vs 1POP	55.15±21.5	57.4±24.37	0.6219
	PREOP vs 2POP	54.89±21.44	65.76±23.56	0.0358
	PREOP vs 3POP	52.85±21.21	57.61±20.64	0.2781
	1POP vs 2POP	56.41±25.04	64.65±23.87	0.1782
	1POP vs 3POP	57.03±26.27	57.38±22.07	0.7078
	2POP vs 3POP	66.83±23.34	57.16±21.06	0.0156

*PREOP = preoperative, 1POP = 1. postoperative, 2POP = 2. Postoperative, 3POP = 3. post-operative measurement

In particular, student paired t-test or Wilcoxon signed rank test shows (see Table 9) that there were significant differences between PREOP and measurement days 1-3 post-operative measurement days of the SNS index and PNS index. The significant level (p-value) was less than 0.05.

4.3.2 Statistical Tests for Surgery Group PR

Table 10. PNS index, SNS index, STD RR, RMSSD, Alpha 1, LF [n.u.] and HF [n.u.] are presented as mean \pm SD for surgery group PR on comparison between different measurement days. Student paired t-test for normally distributed data and Wilcoxon signed rank test for not normally distributed data between different measurement days of surgery group PR.

Parameter	Comparison	Mean \pm SD		p value
PNS index	PREOP vs 1POP	0.25 \pm 1.63	0.07 \pm 1.65	0.3574
	PREOP vs 2POP	0.11 \pm 1.59	-0.15 \pm 1.78	0.4051
	1POP vs 2POP	0.04 \pm 1.62	-0.1 \pm 1.82	0.4321
SNS index	PREOP vs 1POP	0.58 \pm 1.5	1.6 \pm 2.4	0.0429
	PREOP vs 2POP	0.65 \pm 1.55	1.97 \pm 2.42	0.002
	1POP vs 2POP	1.57 \pm 2.46	2.01 \pm 2.48	0.3451
STD RR	PREOP vs 1POP	39.13 \pm 33.42	32.94 \pm 33.96	0.1944
	PREOP vs 2POP	35.61 \pm 30.14	33.29 \pm 40.54	0.7217
	1POP vs 2POP	30.92 \pm 31.17	33.92 \pm 41.55	0.651
RMSSD	PREOP vs 1POP	48.77 \pm 49.1	43.76 \pm 49.94	0.4797
	PREOP vs 2POP	44 \pm 44.7	43 \pm 56	0.911
	1POP vs 2POP	40.78 \pm 45.67	43.84 \pm 57.38	0.7314
Alpha 1	PREOP vs 1POP	0.89 \pm 0.3	0.8 \pm 0.36	0.1941
	PREOP vs 2POP	0.9 \pm 0.31	0.88 \pm 0.39	0.8522
	1POP vs 2POP	0.8 \pm 0.36	0.87 \pm 0.4	0.1433
LF [n.u.]	PREOP vs 1POP	51.08 \pm 22.33	47.29 \pm 25.17	0.5563
	PREOP vs 2POP	51.8 \pm 22.26	50.06 \pm 25.85	0.6462
	1POP vs 2POP	46.85 \pm 25.39	49.76 \pm 26.21	0.414
HF [n.u.]	PREOP vs 1POP	48.66 \pm 22.18	52.4 \pm 24.95	0.566
	PREOP vs 2POP	47.94 \pm 22.11	49.69 \pm 25.67	0.6566
	1POP vs 2POP	52.84 \pm 25.16	49.97 \pm 26.03	0.423

*PREOP = preoperative, 1POP = 1. postoperative, 2POP = 2. Postoperative

The Student paired t-test or Wilcoxon signed rank test shows (see Table 10) that there was no significant difference in the selected HRV parameters between measurement days. The significant level (p-value) was less than 0.05.

4.3.3 Statistical Tests for Surgery Group PM

Table 11. PNS index, SNS index, STD RR, RMSSD, Alpha 1, LF [n.u.] and HF [n.u.] are presented as mean \pm SD for surgery group PM on comparison between different measurement days. Student paired t-test for normally distributed data and Wilcoxon signed rank test for not normally distributed data between different measurement days of surgery group PM.

Parameter	Comparison	Mean \pm SD		p value
PNS index	PREOP vs 1POP	0.17 \pm 2.09	0.56 \pm 2.64	0.1658
	PREOP vs 2POP	0.28 \pm 2.28	0.25 \pm 2.41	0.9167
	1POP vs 2POP	0.47 \pm 2.56	0.17 \pm 2.42	0.3168
SNS index	PREOP vs 1POP	0.82 \pm 1.83	0.67 \pm 1.95	0.5645
	PREOP vs 2POP	0.68 \pm 1.72	1.23 \pm 2.26	0.184
	1POP vs 2POP	0.71 \pm 1.94	1.37 \pm 2.24	0.0393
STD RR	PREOP vs 1POP	40.61 \pm 38.89	41.22 \pm 49.9	0.9088
	PREOP vs 2POP	42.06 \pm 40.98	41.73 \pm 47.94	0.9498
	1POP vs 2POP	39.69 \pm 48.82	41.84 \pm 49.43	0.7311
RMSSD	PREOP vs 1POP	50.97 \pm 61.94	55.12 \pm 80.71	0.6307
	PREOP vs 2POP	53.03 \pm 66.28	53.59 \pm 71.88	0.9379
	1POP vs 2POP	52.4 \pm 78.8	53.58 \pm 73.97	0.9026
Alpha 1	PREOP vs 1POP	0.95 \pm 0.33	0.83 \pm 0.31	0.0025
	PREOP vs 2POP	0.95 \pm 0.32	0.93 \pm 0.35	0.3285
	1POP vs 2POP	0.83 \pm 0.31	0.94 \pm 0.36	0.0396
LF [n.u.]	PREOP vs 1POP	55.28 \pm 21.37	46.71 \pm 23.04	0.0147
	PREOP vs 2POP	55.17 \pm 19.37	51.04 \pm 22.56	0.0947
	1POP vs 2POP	47.09 \pm 22.92	51.69 \pm 22.8	0.1922
HF [n.u.]	PREOP vs 1POP	44.55 \pm 21.23	53.03 \pm 22.83	0.0153
	PREOP vs 2POP	44.67 \pm 19.22	48.75 \pm 22.41	0.0947
	1POP vs 2POP	52.67 \pm 22.72	48.1 \pm 22.65	0.1876

*PREOP = preoperative, 1POP = 1. postoperative, 2POP = 2. Postoperative

The Student paired t-test or Wilcoxon signed rank test shows (see Table 11) that there was significant difference in the selected HRV parameters (Alpha 1 and LF [n.u.] and HF [n.u.]) between PREOP and 1POP. The Student paired t-test or Wilcoxon signed rank test shows that there was no significant difference in the selected HRV parameters between other measurement comparisons except 1POP vs 2POP of PNS index. The significant level (p-value) was less than 0.05.

4.4 Statistical Tests for Two Different Intervention Groups

4.4.1 Intervention Groups of All Surgery Groups

Table 12. Difference between different measurement days, PNS index, SNS index, STD RR, RMSSD, Alpha 1, LF [n.u.] and HF [n.u.] are presented as mean \pm SD for different intervention group. Student unpaired t-test for normally distributed data and Wilcoxon rank sum test for not normally distributed data between different intervention groups (A & B).

Parameter	Difference and comparison	Mean \pm SD		p value
		A	B	
PNS index	PREOP & 1POP	0.52 \pm 2.41	0.01 \pm 2.25	0.3499
	PREOP & 2POP	0.69 \pm 2.28	0.28 \pm 2.28	0.3434
	PREOP & 3POP	0.84 \pm 3.37	0.52 \pm 1.89	0.9999
	1POP & 2POP	0.01 \pm 1.79	0.22 \pm 2.37	0.624
	1POP & 3POP	-0.48 \pm 2.62	0.33 \pm 1.78	0.3079
	2POP & 3POP	-0.43 \pm 2.01	0.32 \pm 1.37	0.2475
SNS index	PREOP & 1POP	-0.7 \pm 2.63	-0.61 \pm 2.55	0.5222
	PREOP & 2POP	-1.11 \pm 2.41	-0.92 \pm 2.41	0.7499
	PREOP & 3POP	-0.78 \pm 1.83	-1.24 \pm 3.06	0.9349
	1POP & 2POP	-0.43 \pm 2.9	-0.32 \pm 1.85	0.7061
	1POP & 3POP	0.3 \pm 2.81	-0.44 \pm 1.95	0.2875
	2POP & 3POP	0.12 \pm 1.91	-0.2 \pm 1.62	0.7701
STD RR	PREOP & 1POP	15.71 \pm 47.06	3.63 \pm 40.56	0.1507
	PREOP & 2POP	15.53 \pm 48.68	2.32 \pm 50.04	0.1577
	PREOP & 3POP	11.93 \pm 69.14	3.25 \pm 39.12	0.6588
	1POP & 2POP	-3.62 \pm 39.69	-2.97 \pm 51.91	0.9432
	1POP & 3POP	-19.34 \pm 58.98	-3.93 \pm 30.94	0.3744
	2POP & 3POP	-21.29 \pm 48.54	2.83 \pm 26.96	0.1294
RMSSD	PREOP & 1POP	17.55 \pm 70.36	1.46 \pm 63.55	0.2091
	PREOP & 2POP	17.59 \pm 72.67	2.4 \pm 72.5	0.2682
	PREOP & 3POP	12.01 \pm 107.37	-0.14 \pm 54.01	0.8831
	1POP & 2POP	-5.11 \pm 65.03	-1.74 \pm 78.89	0.8131
	1POP & 3POP	-24.6 \pm 97.87	-3.52 \pm 43.88	0.3744
	2POP & 3POP	-28.08 \pm 73	4.74 \pm 41.21	0.1294
Alpha 1	PREOP & 1POP	0.13 \pm 0.28	0.08 \pm 0.34	0.4363
	PREOP & 2POP	0.08 \pm 0.36	-0.01 \pm 0.4	0.3478
	PREOP & 3POP	0.18 \pm 0.34	0.09 \pm 0.37	0.5021
	1POP & 2POP	-0.05 \pm 0.32	-0.07 \pm 0.36	0.656
	1POP & 3POP	0.03 \pm 0.51	-0.04 \pm 0.48	0.9141
	2POP & 3POP	0.03 \pm 0.51	0.02 \pm 0.39	0.8001
LF [n.u.]	PREOP & 1POP	3.23 \pm 24.82	7.15 \pm 24.66	0.2871
	PREOP & 2POP	5.63 \pm 24.26	5.02 \pm 26.97	0.763
	PREOP & 3POP	4.67 \pm 27.03	7.92 \pm 25.4	0.8318
	1POP & 2POP	1.29 \pm 24.54	-2.39 \pm 26.5	0.3166
	1POP & 3POP	-0.16 \pm 33.83	0.92 \pm 33.73	0.846

	2POP & 3POP	-9.14±18.73	-9.37±18.78	0.8609
HF [n.u.]	PREOP & 1POP	-3.19±24.67	-7.01±24.47	0.3146
	PREOP & 2POP	-5.51±24.1	-4.92±26.77	0.763
	PREOP & 3POP	-4.45±26.89	-7.76±25.19	0.8318
	1POP & 2POP	-1.21±24.42	2.36±26.3	0.3166
	1POP & 3POP	0.23±33.61	-0.94±33.13	0.846
	2POP & 3POP	9.11±18.55	9.2±18.5	0.8609

*PREOP = preoperative, 1POP = 1. postoperative, 2POP = 2. Postoperative

The Student unpaired t-test or Wilcoxon rank sum test shows (see Table 12) that there was no significant difference in the selected HRV parameters between measurement days. The significant level (p-value) was less than 0.05.

4.4.2 Intervention Groups of Surgery Group C

Table 13. Difference between different measurement days, PNS index, SNS index, STD RR, RMSSD, Alpha 1, LF [n.u.] and HF [n.u.] are presented as mean \pm SD for different intervention group. Student unpaired t-test for normally distributed data and Wilcoxon rank sum test for not normally distributed data between different intervention groups (A & B).

Parameter	Difference and comparison	Mean \pm SD		p value
		A	B	
PNS index	PREOP & 1POP	1.07 \pm 3.83	1.43 \pm 2.35	0.6539
	PREOP & 2POP	1.94 \pm 3.19	0.8 \pm 3.04	0.3414
	PREOP & 3POP	1.01 \pm 3.39	1.03 \pm 1.09	0.8368
	1POP & 2POP	0.2 \pm 2.2	-0.64 \pm 3.62	0.6177
	1POP & 3POP	-0.42 \pm 2.7	0.38 \pm 1.91	0.3842
	2POP & 3POP	-0.36 \pm 2.05	0.26 \pm 1.39	0.3389
SNS index	PREOP & 1POP	-0.98 \pm 3.6	-1.68 \pm 2.42	0.7405
	PREOP & 2POP	-1.17 \pm 2.48	-1.38 \pm 2.83	0.926
	PREOP & 3POP	-0.95 \pm 1.7	-1.77 \pm 2.9	0.6395
	1POP & 2POP	0.01 \pm 3.06	0.2 \pm 2.23	0.9639
	1POP & 3POP	0.25 \pm 2.9	-0.34 \pm 2.12	0.443
	2POP & 3POP	-0.04 \pm 1.86	-0.19 \pm 1.7	0.9639
STD RR	PREOP & 1POP	28.28 \pm 77.81	27.01 \pm 46.25	1
	PREOP & 2POP	45.48 \pm 68.36	10.74 \pm 69.4	0.2388
	PREOP & 3POP	13.94 \pm 70.57	13.25 \pm 20.69	0.7788
	1POP & 2POP	4.69 \pm 53.06	-16.88 \pm 69.89	0.586
	1POP & 3POP	-19.7 \pm 61.04	0.01 \pm 26.09	0.3565
	2POP & 3POP	-21.27 \pm 50.24	2.17 \pm 28.24	0.2352
RMSSD	PREOP & 1POP	30.44 \pm 116.65	36.26 \pm 71.09	0.5717
	PREOP & 2POP	58.64 \pm 107.71	10.61 \pm 105.81	0.3809
	PREOP & 3POP	15.06 \pm 109.63	13.76 \pm 27.63	1
	1POP & 2POP	9.69 \pm 93.82	-26.74 \pm 114.15	0.3701
	1POP & 3POP	-24.11 \pm 101.28	1.97 \pm 41.4	0.3565
	2POP & 3POP	-27.21 \pm 75.48	2.74 \pm 42.96	0.2539
Alpha 1	PREOP & 1POP	0.17 \pm 0.38	0.01 \pm 0.39	0.2995
	PREOP & 2POP	0.17 \pm 0.51	-0.01 \pm 0.47	0.2703
	PREOP & 3POP	0.16 \pm 0.34	0.05 \pm 0.38	0.3772
	1POP & 2POP	-0.01 \pm 0.34	0.06 \pm 0.45	0.7856
	1POP & 3POP	0 \pm 0.51	-0.03 \pm 0.5	0.9188
	2POP & 3POP	0.01 \pm 0.51	0.05 \pm 0.42	0.8562
LF [n.u.]	PREOP & 1POP	3.5 \pm 25.77	1.2 \pm 31.44	0.9224
	PREOP & 2POP	11.26 \pm 30.51	11.09 \pm 30	0.9556
	PREOP & 3POP	3.68 \pm 27.46	6.56 \pm 26.14	0.8368
	1POP & 2POP	6.42 \pm 28.21	10.7 \pm 33.62	0.4672
	1POP & 3POP	-1.84 \pm 34.32	3.44 \pm 35.98	0.8384
	2POP & 3POP	-10.65 \pm 18.34	-8.81 \pm 20.01	0.8207
HF [n.u.]	PREOP & 1POP	-3.36 \pm 25.63	-1.07 \pm 31.11	0.9845

	PREOP & 2POP	-10.92±30.39	-10.81±29.62	0.9556
	PREOP & 3POP	-3.45±27.3	-6.44±25.95	0.8368
	1POP & 2POP	-6.26±28.11	-10.51±33.37	0.5551
	1POP & 3POP	1.9±34.1	-3.43±35.35	0.8384
	2POP & 3POP	10.6±18.18	8.6±19.71	0.8207

*PREOP = preoperative, 1POP = 1. postoperative, 2POP = 2. Postoperative

The Student unpaired t-test or Wilcoxon rank sum test shows (see Table 13) that there was no significant difference in the selected HRV parameters between measurement days. The significant level (p-value) was less than 0.05.

4.4.3 Intervention Groups of Surgery Group PR

Table 14. Difference between different measurement days, PNS index, SNS index, STD RR, RMSSD, Alpha 1, LF [n.u.] and HF [n.u.] are presented as mean \pm SD for different intervention group. Student unpaired t-test for normally distributed data and Wilcoxon rank sum test for not normally distributed data between different intervention groups (A & B).

Parameters	Difference and Comparison	Mean \pm SD		p value
		A	B	
PNS index	PREOP & 1POP	0.4 \pm 1.09	-0.03 \pm 2.32	0.3854
	PREOP & 2POP	0.22 \pm 1.51	0.29 \pm 2.24	0.8175
	1POP & 2POP	-0.14 \pm 1.01	0.42 \pm 1.79	0.2562
SNS index	PREOP & 1POP	-0.76 \pm 2.62	-1.27 \pm 3.01	0.84
	PREOP & 2POP	-1.1 \pm 2.79	-1.54 \pm 2.12	0.3249
	1POP & 2POP	-0.46 \pm 3.36	-0.41 \pm 2.04	0.9378
STD RR	PREOP & 1POP	10 \pm 19.35	2.37 \pm 36.14	0.5635
	PREOP & 2POP	5.58 \pm 21.14	-0.95 \pm 52.81	0.3249
	1POP & 2POP	-3.85 \pm 22.72	-2.16 \pm 51.91	0.9875
RMSSD	PREOP & 1POP	11.05 \pm 27.4	-1.03 \pm 54.96	0.6235
	PREOP & 2POP	2.94 \pm 38.36	-0.94 \pm 68.31	0.8304
	1POP & 2POP	-7.59 \pm 38.23	1.47 \pm 65.5	0.6161
Alpha 1	PREOP & 1POP	0.1 \pm 0.28	0.08 \pm 0.37	0.6861
	PREOP & 2POP	0.06 \pm 0.36	-0.03 \pm 0.42	0.6441
	1POP & 2POP	-0.03 \pm 0.33	-0.12 \pm 0.32	0.5212
LF [n.u.]	PREOP & 1POP	1.26 \pm 24.35	6.31 \pm 22.31	0.4879
	PREOP & 2POP	4.19 \pm 25.64	-0.7 \pm 28.94	0.7729
	1POP & 2POP	1.09 \pm 13.75	-6.9 \pm 19.63	0.1341
HF [n.u.]	PREOP & 1POP	-1.29 \pm 24.17	-6.2 \pm 22.12	0.5063
	PREOP & 2POP	-4.16 \pm 25.4	0.66 \pm 28.81	0.7729
	1POP & 2POP	-1.02 \pm 13.57	6.76 \pm 19.48	0.1427

*PREOP = preoperative, 1POP = 1. postoperative, 2POP = 2. Postoperative

The Student unpaired t-test or Wilcoxon rank sum test shows (see Table 14) that there was no significant difference in the selected HRV parameters between measurement days. The significant level (p-value) was less than 0.05.

4.4.4 Intervention Groups of Surgery Group PM

Table 15. Difference between different measurement days, PNS index, SNS index, STD RR, RMSSD, Alpha 1, LF [n.u.] and HF [n.u.] are presented as mean \pm SD for different intervention group. Student unpaired t-test for normally distributed data and Wilcoxon rank sum test for not normally distributed data between different intervention groups (A & B).

Parameters	Difference and Comparison	Mean \pm SD		P value
		A	B	
PNS index	PREOP & 1POP	0.18 \pm 1.85	-0.92 \pm 1.64	0.05
	PREOP & 2POP	0.16 \pm 1.69	-0.1 \pm 1.63	0.4626
	1POP & 2POP	0.01 \pm 2.06	0.59 \pm 1.71	0.3416
SNS index	PREOP & 1POP	-0.43 \pm 1.68	0.67 \pm 1.54	0.0302
	PREOP & 2POP	-1.08 \pm 2.08	-0.04 \pm 2.13	0.2043
	1POP & 2POP	-0.72 \pm 2.41	-0.58 \pm 1.37	0.5831
STD RR	PREOP & 1POP	11.07 \pm 31.18	-11.22 \pm 33.76	0.0318
	PREOP & 2POP	1.7 \pm 39.98	-0.99 \pm 27.78	0.8003
	1POP & 2POP	-9.65 \pm 41.01	5.34 \pm 37.26	0.234
RMSSD	PREOP & 1POP	13.42 \pm 49.16	-20.11 \pm 57.1	0.0476
	PREOP & 2POP	-0.43 \pm 51.03	-0.69 \pm 44.14	0.9855
	1POP & 2POP	-13.98 \pm 59.33	11.61 \pm 60.7	0.1855
Alpha 1	PREOP & 1POP	0.12 \pm 0.21	0.13 \pm 0.29	0.7365
	PREOP & 2POP	0.03 \pm 0.19	0 \pm 0.35	0.9329
	1POP & 2POP	-0.09 \pm 0.29	-0.12 \pm 0.33	0.7584
LF [n.u.]	PREOP & 1POP	4.87 \pm 25.66	11.92 \pm 21.39	0.3487
	PREOP & 2POP	2.65 \pm 17.1	5.55 \pm 22.84	0.3286
	1POP & 2POP	-2.37 \pm 29.28	-6.83 \pm 25.13	0.4777
HF [n.u.]	PREOP & 1POP	-4.87 \pm 25.51	-11.76 \pm 21.32	0.3487
	PREOP & 2POP	-2.62 \pm 17.05	-5.47 \pm 22.77	0.3408
	1POP & 2POP	2.39 \pm 29.17	6.75 \pm 25.01	0.4777

*PREOP = preoperative, 1POP = 1. postoperative, 2POP = 2. Postoperative

The Student unpaired t-test or Wilcoxon rank sum test shows (see Table 15) that there was no significant difference in the selected HRV parameters between measurement days except comparison pair PREOP and 1POP of SNS index, STD RR and RMSSD. The significant level (p-value) was less than 0.05.

5. DISCUSSION

The clinicians acknowledged ECG measurement, and it was simple to perform the measurement procedure among normal patient care. Just a few patients had refused to take part in the study. Since the entire study protocol included a 30-minute IP and spirometry measurement session, other individual assessments, and regular physiotherapy lessons, coordination between the schedules of the patient and physiotherapist has been challenging from time to time.

The results and further effectiveness of this study are discussed. Some errors and difficulties are also discussed. The results including all HRV parameters are presented in appendix.

5.1 Effective RR Interval Measurement

The QRS detection algorithm could not detect QRS complex 100% accurately. Some of the measurements were excluded from the study because the algorithm did not detect R peaks correctly. If 95% of R-peaks were observed by the QRS identification algorithm then RR intervals were measured. The measurements were excluded from the study if it was less than 95%. Only measurements with detection of 95% R-peaks were included in this study to measure the RR interval.

The detection accuracy was visually checked and it was time consuming. However, It was important to see that most of the R peaks of a measurement were detected correctly. 10-11% of the measurements were excluded from study due to less than 95% detection of R peaks. There might be several reasons for that poor detection. ECG signals might be too noisy for detecting right R peaks as well as the algorithm filter was not working correctly with those signals. Some other algorithms might be useful in those cases but those signals had very irregular R peaks. Depending on the signal availability and quality, a few measure-

ments were excluded from the study before using QRS detection algorithm. Because those signals were distorted, noisy and some measurements did not have post-operative days measurements.

5.2 Error Origins in Measurement Setup

The study was conducted between normal hospital practices, so redoing the measurements or testing the ECG records was not usually possible. Additionally, if the measurement device was not functioning correctly, an expert was not qualified to repair it immediately. In measurement of this study, the electrode configuration was followed according Seppä et al.[39]. Młyńczak et al.[32] reported that the electrode configuration validated by Seppä et al.[39] is suitable under static conditions, but the configuration should be less prone to motion artefacts for ambulatory measurements.

ECGs contaminated by artefacts or noise conflict the normal functioning of the automatic analysis algorithm[21]. Motion artefacts were one of the most frequent explanations in the study for excluding a measurement. This was already done at study start when all ECG signals were visually checked. If the patient shifted rapidly the ECG signal was very skewed and there was no regular RR interval present at all. This triggered rapid changes in signal amplitude in the ECG, a continuous signal of zero amplitude and a gradual decrease in the waveform of the ECG signals. Unable to interpret these signals.

Motion artefacts are part of the transient change of baseline caused by the movements of the electrode which are the result of movement of a subject. There are several experiments using the filtered or differential approach to minimize motion artefacts.[27]

When improving the measurement setup these signal errors should be carefully considered. More detailed explanations for the errors should be identified. To determine if the cause was due to the behaviour of the researcher or patient, and if the errors could be avoided in further tests.

5.3 Statistical Analysis

The comparison between different measurement days was selected depending on the distribution of HRV parameters. When the HRV parameters of both days were normally distributed then, the student paired t test was used. Whereas, Wilcoxon signed rank test was performed between different measurement days. Student paired t test and Wilcoxon signed rank test are used for dependent samples. In this study, PREOP and 1POP,2POP,3POP were dependent samples because same patient has PREOP measurement and post operational measurements.

The t-test was used to determine if the means of different days of HRV parameters were significantly different from each other. The results showed that some of the parameters are significantly different from different measurement days. The results showed that in surgery group C, PNS index and SNS index are significantly different from PREOP to 1-3 POP. In other surgery groups, significant difference was not consistently observed. Most possibly, this is due to minimally invasive procedure of thoracic surgery.

5.4 The Effect of Intervention

All patients were randomized into two subgroups: control group (A) and study group (B). Both groups received different physiotherapy interventions: group A received traditional expiration-focused PEP-P physiotherapy and group B received inspiration-focused IMT-P. No significant differences were found in HRV parameters except surgery group PM. The results showed that the HRV parameters were not significantly different for different measurement days.

The preliminary randomized controlled clinical study shows that when the respiration is tested using spirometry, there is a significant difference in recovery between intervention approaches in cardiac patients. However, intervention approaches did not have significant effect in this study. In surgery group PM, there were some selected HRV parameters (see table 15) have significant differences between PREOP and 1POP.

5.5 HRV in Evaluation of Recovery Phase

The recovery phase could not be identified with this study. Most possibly, this is because of the only 2-3 days' timeframe tracked. The reported recovery of autonomic function was linked to an observation period of 12 weeks[2]. The results published by Soares et al.[42] support this theory by identifying a decrease in autonomic function immediately following coronary artery surgery which is most distinct 6 days after surgery.

Since the surgery groups PM and PR not directly affect the heart hence significant differences of HRV parameters between different measurement days were not consistently observed. The main objective of an improved recovery program following thoracic surgery is to minimize stress response, reduce postoperative pulmonary complications and improve patient outcomes, which will also decrease hospital stay and lower hospital costs. Video-assisted thoracoscopic surgery as a minimally invasive procedure represents an important part of an improved recovery program in thoracic surgery[5].

6. CONCLUSION

For use of appropriate methods in HRV analysis, the actual physiological effect on variability in RR intervals and in HR should be studied more precisely. The effects of various cardiac and neural diseases on HRV are not widely studied, and the use of RR intervals in large numbers of HRV studies has shown that variations in RR intervals have important prognostic value in the cardiac mortality.

The effect of cardiothoracic surgery to the HRV is difficult to generalize. The patients perioperatively had different diagnoses and general conditions, and the success during the tests relied on the patient's actual condition as well as the subjective perception of the pain or the orientation-affecting drugs.

It has been shown that open chest surgery is not only associated with a reduction in autonomic cardiovascular activity, but that there is a strong relationship between the type of surgery and its effects on the cardiovascular variability. In particular, PR and PM surgery showed to be beneficial in terms of maintaining autonomic activities compared to surgery group C. For Minimally invasive thoracic surgery or some other reasons, the significant differences were not consistently found in surgery group PR and PM. Depending on the types of cardiac surgeries, it can be studied in further.

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APPENDIX A: RESULTS OF INTERVENTION FOR ALL GROUPS

Results of interventions for all surgery group including all HRV parameters:

Parameters	Mean ± SD											
	A						B					
	01	02	03	12	13	23	01	02	03	12	13	23
PNS.index	0.52±2.41	0.69±2.28	0.84±3.37	0.01±1.79	-0.48±2.62	-0.43±2.01	0.01±2.25	0.28±2.28	0.52±1.89	0.22±2.37	0.33±1.78	0.32±1.37
SNS.index	-0.7±2.63	-1.11±2.41	-0.78±1.83	-0.43±2.9	0.3±2.81	0.12±1.91	-0.61±2.55	-0.92±2.41	-1.24±3.06	-0.32±1.85	-0.44±1.95	-0.2±1.62
Stress.index	-4.28±13.61	-5.71±12.65	-0.29±5.5	-1.68±17.91	4.01±15.53	4.38±9.33	-4.15±11.68	-4.27±12.07	-4.14±14.83	-0.15±9.4	0.31±8.21	-0.43±8.4
Mean.RR...ms	24.94±165.5	74.74±156.1	136.31±295.77	39.45±113.18	38.15±234.09	30.25±200.68	25.43±158.97	71.33±142.1	152.39±170.29	48.87±96.12	99.27±153.96	2.25±103.58
STD.RR...ms.	15.71±47.06	15.53±48.68	11.93±69.14	-3.62±39.69	-19.34±58.98	-21.29±48.54	3.63±40.56	2.32±50.04	3.25±39.12	-2.97±51.91	-3.93±30.94	2.83±26.96
Mean.HR..beats.min.	-1.68±12.75	-5.44±11.63	-13.08±24.05	-3.05±11.55	-5.09±22.35	-5.99±16.37	-1.86±12.82	-5.68±11.77	-12.03±14.26	-3.99±8.57	-8.06±13.47	0.86±10.6
STD.HR..beats.min.	1.19±5.06	0.62±4.52	-2.68±7.86	-0.34±6.61	-3.64±14.09	-4.26±9.78	-0.01±3.65	-0.88±5.49	-0.73±3.96	-0.94±6.46	-1.32±3.82	1.29±3.44
Min.HR..beats.min.	-3.66±12.94	-6.56±12.18	-9.62±19.16	-2.59±9.52	-1.72±12.2	-1.39±11.27	-2.95±13.08	-5.6±11.54	-10.13±14.57	-2.72±8.16	-4.41±10.36	0.33±10.96

Max.HR..beat s.min.	1.81±16.77	-2.18±16.05	- 13.02±31.66	- 3.15±19.5 5	-8.43±38.21	-10.2±26.29	- 1.76±16.1 2	- 6.32±17.2 7	- 13.74±15. 33	-5.1±17.79	- 10.71±17. 07	2.37±11.2 9
RMSSD..ms.	17.55±70.36	17.59±72.67	12.01±107.3 7	- 5.11±65.0 3	-24.6±97.87	-28.08±73	1.46±63.5 5	2.4±72.5	- 0.14±54.0 1	-1.74±78.89	- 3.52±43.8 8	4.74±41.2 1
NNxx..beats.	21.07±132.7 6	7.55±187.71	- 45.47±274.2 1	- 12.32±226 .73	- 75.38±408. 27	- 149.62±280 .02	15.3±134. 9	- 1.82±128. 13	- 23.81±178 .27	- 9.98±142.9 1	- 41.54±178 .06	7.87±51.1 1
pNNxx....	4.69±18.73	3.23±26.12	1.1±29.47	- 2.26±23.9 9	-8.66±40.18	- 15.94±28.2 6	2.62±21	1.07±17.3	- 0.99±23.6 7	-0.11±18.36	-2.1±20.54	0.22±5.6
RR.tri.index	1.75±8.55	2.16±8.8	2.25±11.36	-0.32±5.52	-1.93±13.23	-5.1±8.73	2.23±6.49	1.48±6.97	1.63±9.2	-0.64±4.41	-1.97±7.05	0.3±2.22
TINN..ms.	106.31±377. 71	117.55±351. 08	50.95±446.2 6	1.92±301. 67	- 96.25±429. 89	- 128.81±310 .96	33.25±287 .33	44.67±322 .03	- 11.06±255 .51	16.45±290. 56	- 33.08±148 .54	22.47±310 .84
SD1..ms.	12.42±49.8	12.45±51.43	8.51±75.99	- 3.61±46.0 1	- 17.41±69.2 4	- 19.87±51.6 5	1.03±44.9 7	1.7±51.31	- 0.09±38.2 1	-1.23±55.82	- 2.49±31.0 5	3.35±29.1 6
SD2..ms.	18.78±48.13	17.89±47.67	14.23±63.62	-4.07±33.4	- 23.59±49.6 7	- 22.71±46.6 2	6.1±36.88	2.86±49.8 1	5.92±40.7 4	-4.56±48.89	- 6.14±33.3 8	1.97±25.1 9
SD2.SD1.ratio	0.18±0.57	0.05±0.77	0.34±0.51	-0.17±0.71	0.1±0.71	0.17±0.96	0.09±0.63	-0.08±0.94	0.02±0.88	-0.17±0.82	-0.06±0.96	-0.04±0.53
Approximate.en- tropy..ApEn.	-0.03±0.47	0.04±0.44	0.07±0.59	0.05±0.5	-0.1±0.59	-0.17±0.58	0.07±0.34	0.04±0.41	0.07±0.35	-0.03±0.45	-0.07±0.45	-0.01±0.51
Sample.en- tropy..SampEn.	-0.04±0.72	0.07±0.72	0.17±0.85	0.09±0.76	-0.01±0.86	-0.21±0.82	0.13±0.57	0.09±0.68	0.18±0.59	-0.01±0.69	-0.12±0.69	-0.04±0.7
alpha.1	0.13±0.28	0.08±0.36	0.18±0.34	-0.05±0.32	0.03±0.51	0.03±0.51	0.08±0.34	-0.01±0.4	0.09±0.37	-0.07±0.36	-0.04±0.48	0.02±0.39
alpha.2	-0.01±0.19	-0.05±0.18	-0.03±0.17	-0.04±0.18	0±0.22	0.04±0.18	-0.05±0.22	-0.06±0.18	-0.1±0.28	-0.02±0.19	-0.09±0.31	-0.04±0.19
VLF..Hz..FFT.	0±0.01	0±0.01	0±0.01	0±0.01	0±0.01	0±0.01	0±0.01	0±0.01	0±0.01	0±0.01	0±0.01	0±0
VLF..Hz..AR.	0±0.02	0±0.02	0±0.01	0±0.02	0±0.02	0±0.02	0±0.01	0.01±0.02	0.01±0.02	0±0.02	0.01±0.02	0±0.02
LF..Hz..FFT.	0.01±0.04	0.01±0.04	0.01±0.05	0±0.03	-0.01±0.04	-0.01±0.06	0±0.04	0±0.04	0±0.04	0±0.04	0.01±0.05	0±0.05
LF..Hz..AR.	0±0.04	0.01±0.04	-0.01±0.05	0.01±0.05	-0.01±0.06	-0.02±0.04	0±0.04	0.01±0.05	0±0.06	0.01±0.05	0.01±0.06	0±0.05
HF..Hz..FFT.	-0.01±0.09	-0.03±0.1	-0.06±0.1	-0.02±0.1	-0.02±0.08	0.03±0.09	0±0.08	0±0.07	-0.05±0.08	0±0.08	-0.02±0.1	-0.03±0.08
HF..Hz..AR.	-0.02±0.09	-0.02±0.11	-0.04±0.11	0±0.12	-0.01±0.11	0.03±0.12	-0.01±0.1	0±0.07	-0.01±0.08	0.01±0.09	0.03±0.08	0.01±0.1
VLF..ms.2..FFT.	38.71±153.3 7	55.92±125.9	16.11±173.7	6.99±117. 19	- 20.59±169. 32	- 52.23±121. 98	35.74±202 .03	54.09±242 .35	42.38±190 .77	3.58±162.4 1	- 40.5±94.2 5	- 26.89±50. 8
VLF..ms.2..AR.	105.68±463. 24	117.24±446. 92	138.21±689. 78	- 40.17±303 .14	- 103.21±579 .76	- 187.81±473 .31	22.75±391 .65	12.46±447 .48	31.12±156 .63	- 31.82±309. 32	- 82.27±184 .2	- 20.23±110 .12

LF..ms.2..FFT	541.1±3222.64	913.3±3489.08	1101.45±5430.52	-143.82±1814.95	-96.52±3844.55	-1162.61±2490.48	303.21±2823.79	434.25±2657.32	89.02±1381.24	-29.05±1572.57	-477.83±1141.3	-191.41±794.22
LF..ms.2..AR.	625.31±3136.34	1013.23±3521.94	1850.54±5843.36	-167.36±1575.51	-69.75±3566.33	-960.43±2382.84	255.58±3295.04	441.15±3159.47	359.06±1338.99	28.78±1835.46	-342.79±1006.7	-150.3±697.15
HF..ms.2..FFT	1457.38±7675.48	2178.79±8940.18	4096.2±15757.82	-370.77±2318.88	-1429.69±3488.94	-1165.16±4423.29	75.48±5714.64	466.12±9284.19	238.02±2193.73	989.47±8987.13	-341.05±2903.87	-37.57±804.43
HF..ms.2..AR.	1565.08±7763.49	2081.51±8191.02	3795.74±14151.56	-416.27±2339.11	-1973.62±3915.81	-1460.57±5154.51	229.8±6021.43	-256.65±8649.82	-106.9±2205.06	-875.5±7688.66	-324.79±2846.62	-102.1±1041.82
VLF..log..FFT.	0.75±2.05	0.83±1.83	0.37±2.08	0.01±1.91	-0.42±2.22	-0.55±1.54	0.62±1.63	0.52±1.58	0.49±1.85	-0.12±1.44	-0.72±1.87	-0.55±1.13
VLF..log..AR.	0.86±1.97	0.84±2.01	0.43±1.9	-0.08±2.1	-0.64±2.24	-0.68±2.09	0.47±1.56	0.42±1.76	0.48±1.86	-0.03±1.65	-0.61±1.66	-0.17±1.65
LF..log..FFT.	0.94±2.34	1.12±2.27	0.59±2.53	0.14±2.65	-0.59±2.73	-0.88±2.52	0.69±1.85	0.65±2.02	0.87±2.37	-0.03±1.75	-0.06±1.58	-0.19±1.78
LF..log..AR.	0.99±2.25	1.1±2.12	0.64±2.22	0.05±2.43	-0.63±2.69	-0.75±2.33	0.75±1.72	0.76±2.17	0.79±2.54	0.03±1.95	-0.11±1.44	-0.14±2.25
HF..log..FFT.	0.77±2.58	0.87±2.51	0.41±2.88	0.11±2.72	-0.57±2.56	-0.43±2.18	0.34±2.19	0.44±2.37	0.52±2.67	0.16±2.17	-0.01±1.67	0.33±2.15
HF..log..AR.	0.71±2.4	0.85±2.42	0.05±2.16	0.15±2.56	-0.79±2.7	-0.72±2.22	0.45±2.2	0.63±2.42	0.48±2.64	0.23±2.26	-0.01±1.6	0.08±2.28
VLF.....FFT.	-0.06±11.07	-1.11±10.81	-0.82±10.63	-1.28±11.64	0.73±10.67	-1.7±8.4	-1.27±10.36	-1.65±10.71	-2.99±12.77	-0.51±10.64	-2.82±14.74	-4.1±9.76
VLF.....AR.	0.58±8.99	-0.84±9.3	1.88±7.57	-1.69±9.02	0.76±9.95	0.73±8.46	-2.13±9.19	-2.67±9.22	-3.47±13.48	-0.5±9.92	-3.53±19.15	-2.4±8.01
LF.....FFT.	3.34±20.41	6.25±20.38	4.84±22.28	1.97±19.96	-0.56±28.74	-7.27±18.34	7.75±20.42	6.16±22.07	9.54±18.46	-2.04±21.82	1.47±24.74	-6.97±14.86
LF.....AR.	4.9±17.76	5.97±19.48	10.7±21.86	-0.11±18.17	3.63±30.09	-0.54±22.97	6.85±19.16	5.06±20.62	8.71±20.17	-2.15±19.7	-0.41±20.82	-3.01±13.54
HF.....FFT.	-3.25±24.84	-5.03±24.99	-3.82±27.48	-0.62±25.29	-0.1±34.23	8.95±19.2	-6.36±25.67	-4.43±27.38	-6.4±27.67	2.52±27.14	1.33±36.27	10.89±21
HF.....AR.	-5.4±21.59	-5.01±25.67	-12.37±26.08	1.83±23.25	-4.29±37.85	-0.17±28.31	-4.67±25.05	-2.34±25.4	-5.13±26.99	2.65±24.91	3.88±37.2	5.35±18.18
LF..n.u...FFT.	3.23±24.82	5.63±24.26	4.67±27.03	1.29±24.54	-0.16±33.83	-9.14±18.73	7.15±24.66	5.02±26.97	7.92±25.4	-2.39±26.5	0.92±33.73	-9.37±18.78
LF..n.u...AR.	5.59±22.09	5.57±25.57	12.74±25.76	-1.47±23.08	4.52±37.84	-0.06±28.67	5.84±24.33	3.71±25.94	6.38±27.16	-2.41±24.99	-1.3±33.46	-4.64±17.74
HF..n.u...FFT.	-3.19±24.67	-5.51±24.1	-4.45±26.89	-1.21±24.42	0.23±33.61	9.11±18.55	-7.01±24.47	-4.92±26.77	-7.76±25.19	2.36±26.3	-0.94±33.13	9.2±18.5

HF..n.u...AR.	-5.51±21.95	-5.45±25.46	- 12.52±25.55	1.5±23	-4.41±37.45	0.08±28.33	- 5.78±24.17	-3.64±25.8	- 6.26±27.06	2.41±24.83	1.24±33.13	4.57±17.58
To- tal.power...ms. 2..FFT.	2039.19±10721.89	3149.99±12299.05	5208.49±20798.86	- 509.25±4019.5	- 1558.29±7077.9	- 2387.39±6606.2	260.07±8454.95	16.41±11529.46	- 106.71±3568.73	- 1019.25±9913.33	- 866.65±3842.79	- 254.22±1581.19
To- tal.power...ms. 2..AR.	2301.78±11147.46	3218.11±11939.9	5792±20263.37	- 625.14±4058.62	- 2163.59±7349.43	- 2612.56±7663.29	508.66±9476.58	194.6±11749.06	280.82±3543.14	- 882.05±9023.89	- 754.59±3871.53	- 273.17±1761.18
LF.HF.ra- tio.FFT.	0.05±3.28	-0.73±7.02	0.08±1.89	-0.87±5.29	0.33±1.91	2.15±10.13	0.05±3.04	-0.6±4.41	0.31±1.3	-0.56±4.75	0.53±1.75	-0.24±0.81
LF.HF.ra- tio.AR.	0.31±2	-0.56±4.79	0.55±1.04	-0.97±4.32	0.38±1.93	1.73±7.89	-0.06±2.09	-0.68±4.34	0.29±1.55	-0.68±4.47	0.51±1.84	-0.09±0.9

01 means difference between one day before surgery and 1 day after surgery, 02 means difference between one day before surgery and 2 day after surgery, 03 means difference between one day before surgery and 3 day after surgery, 12 means difference between 1 day after surgery and 2 day after surgery, 13 means difference between 1 day after surgery and 3 day after surgery and 23 means difference between 2 day after surgery and 3 day after surgery. Significant differences between different measurement days were not found.

APPENDIX B: RESULTS OF INTERVENTION FOR DIFFERENT GROUPS

Results of interventions for surgery group C including all HRV parameters:

Parameters	Mean \pm SD											
	A						B					
	01	02	03	12	13	23	01	02	03	12	13	23
PNS.index	1.07 \pm 3.83	1.94 \pm 3.19	1.01 \pm 3.39	0.2 \pm 2.2	-0.42 \pm 2.7	-0.36 \pm 2.05	1.43 \pm 2.35	0.8 \pm 3.04	1.03 \pm 1.09	-0.64 \pm 3.62	0.38 \pm 1.91	0.26 \pm 1.39
SNS.index	-0.98 \pm 3.6	-1.17 \pm 2.48	-0.95 \pm 1.7	0.01 \pm 3.06	0.25 \pm 2.9	-0.04 \pm 1.86	-1.68 \pm 2.42	-1.38 \pm 2.83	-1.77 \pm 2.9	0.2 \pm 2.23	-0.34 \pm 2.12	-0.19 \pm 1.7
Stress.index	-4.48 \pm 17.08	-5.5 \pm 12.5	-0.81 \pm 5.17	-0.7 \pm 19.41	4.06 \pm 16.07	3.75 \pm 9.3	-7.3 \pm 10.72	-4.67 \pm 14.76	-	6.38 \pm 14.43	2.15 \pm 11.12	0.14 \pm 8.98
Mean.RR...ms.	74.19 \pm 250.51	134.9 \pm 214.74	151.78 \pm 296.33	14.87 \pm 152.9	41.74 \pm 241.85	34.82 \pm 206.85	109.32 \pm 156.49	164.4 \pm 127.87	178.25 \pm 163.7	63.6 \pm 101.02	89 \pm 166.1	4.49 \pm 105.69
STD.RR..ms.	28.28 \pm 77.81	45.48 \pm 68.36	13.94 \pm 70.57	4.69 \pm 53.06	-	21.27 \pm 50.24	27.01 \pm 46.25	10.74 \pm 69.4	13.25 \pm 20.69	16.88 \pm 69.89	0.01 \pm 26.09	2.17 \pm 28.24
Mean.HR..beats.min.	-5.73 \pm 19.59	-8.62 \pm 15.68	14.36 \pm 24.09	-0.11 \pm 17.2	-5.5 \pm 23.08	-	6.54 \pm 16.79	-9.07 \pm 11.26	14.01 \pm 11.05	14.52 \pm 12.87	-	6.84 \pm 14.39
STD.HR..beat s.min.	1 \pm 8.48	1.69 \pm 6.64	-2.75 \pm 8.09	1.43 \pm 11.17	-	3.81 \pm 14.57	-	4.44 \pm 10.09	1.56 \pm 2.77	-0.57 \pm 4.75	0.21 \pm 2.12	-2.29 \pm 5.49
Min.HR..beat s.min.	-7 \pm 18.53	-10.13 \pm 15.55	10.89 \pm 18.87	-0.8 \pm 10.98	-	1.86 \pm 12.62	-	1.92 \pm 11.46	10.42 \pm 10.82	12.74 \pm 12.36	13.39 \pm 12.33	-3.55 \pm 9.22
Max.HR..beat s.min.	-1.71 \pm 23.02	-4.24 \pm 20.49	14.15 \pm 32.18	0.86 \pm 28.47	-	-9.2 \pm 39.42	-	10.92 \pm 27.06	-	15.82 \pm 12.96	14.13 \pm 14.41	-9.31 \pm 13.5
RMSSD..ms.	30.44 \pm 116.65	58.64 \pm 107.71	15.06 \pm 109.63	9.69 \pm 93.82	24.11 \pm 101.28	27.21 \pm 75.48	36.26 \pm 71.09	10.61 \pm 105.81	13.76 \pm 27.63	26.74 \pm 114.15	1.97 \pm 41.4	2.74 \pm 42.96
NNxx..beats.	37.94 \pm 226.36	91.62 \pm 220.25	47.83 \pm 281.96	63.4 \pm 312.89	-	80.67 \pm 422.03	-	158.93 \pm 287.27	86.13 \pm 146.7	17.81 \pm 125.09	16.43 \pm 94.44	65.54 \pm 167.81
												-4.31 \pm 40.9

pNNxx....	10.73±30.7 3	17.01±32.47	1.2±30.32	4.25±27.8 5	- 9.28±41.51	- 16.89±28.9 8	13.9±24.57	5.19±21.02	4.31±13.75	-7.06±22.36	- 1.75±20.0 3	-0.49±5.62
RR.tri.index	5.05±15.3	7.93±11.58	2.48±11.64	0.65±2.87	2.15±13.66	-5.43±8.93	6.88±9.59	4.21±9.95	4.05±4.34	-2.22±6.07	-0.87±4.59	0.46±1.56
TINN..ms.	156.69±615 .01	245.19±458. 47	71.94±449. 44	33.4±340. 22	- 84.4±442.2 7	- 111.67±31 3.95	117.13±215 .72	74±377.64	33.86±229. 71	- 30.62±288. 93	- 28.18±160 .17	13.85±334 .41
SD1..ms.	21.55±82.5 6	41.51±76.23	10.67±77.5 9	6.86±66.3 8	- 17.06±71.6 6	- 19.25±53.4	25.66±50.3 2	7.51±74.88	9.74±19.55	- 18.92±80.7 8	1.4±29.3	1.94±30.4
SD2..ms.	36.5±79.9	48.2±62.18	16.01±64.9 8	- 0.32±35.8 1	- 24.8±51.17	- 23.28±48.2	27.73±43.2 7	13.47±64.5 2	16.03±23.5 1	- 14.52±57.8 7	-1.7±24.31	2.16±26.4 2
SD2.SD1.ra- tio	0.25±0.7	0.17±1.04	0.33±0.53	-0.1±0.81	0.07±0.72	0.14±0.99	-0.02±0.64	0.05±0.78	-0.02±0.94	0.1±0.75	-0.09±1.02	-0.03±0.56
Approximate.en- tropy..ApEn.	0.13±0.69	0.13±0.45	0.06±0.6	-0.01±0.55	-0.12±0.61	-0.2±0.59	0.16±0.39	0.1±0.54	0.09±0.36	-0.04±0.53	-0.03±0.47	-0.01±0.55
Sample.en- tropy..SampE n.	0.19±1.05	0.27±0.79	0.14±0.87	0.05±0.82	-0.05±0.88	-0.28±0.81	0.35±0.71	0.27±0.9	0.24±0.59	-0.01±0.81	-0.07±0.69	-0.04±0.75
alpha.1	0.17±0.38	0.17±0.51	0.16±0.34	-0.01±0.34	0±0.51	0.01±0.51	0.01±0.39	-0.01±0.47	0.05±0.38	0.06±0.45	-0.03±0.5	0.05±0.42
alpha.2	-0.04±0.26	-0.11±0.19	-0.04±0.16	-0.07±0.16	-0.01±0.23	0.04±0.18	-0.12±0.22	-0.09±0.21	-0.12±0.28	0.02±0.28	-0.05±0.32	-0.02±0.19
VLF..Hz..FFT.	0±0.01	0±0.01	0±0.01	0±0.01	0±0.01	0±0.01	0±0.01	0±0.01	0±0.01	0±0.01	0±0	0±0
VLF..Hz..AR.	0±0.02	0±0.02	0±0.02	0±0.02	0±0.02	0±0.02	0±0.02	0±0.02	0.01±0.02	0±0.02	0.01±0.02	0±0.02
LF..Hz..FFT.	0.02±0.05	0.02±0.05	0.01±0.05	0±0.05	-0.01±0.04	-0.01±0.06	0.01±0.05	0±0.05	0±0.04	0±0.05	0±0.05	0±0.05
LF..Hz..AR.	0±0.05	0.01±0.05	0±0.05	0.02±0.05	-0.01±0.05	-0.02±0.04	0±0.04	-0.01±0.06	0±0.05	-0.01±0.07	0.01±0.06	0.01±0.06
HF..Hz..FFT.	-0.05±0.11	-0.11±0.08	-0.07±0.1	-0.05±0.11	-0.02±0.08	0.03±0.09	-0.04±0.07	-0.02±0.07	-0.04±0.08	0.01±0.08	0±0.1	-0.02±0.07
HF..Hz..AR.	-0.03±0.11	-0.09±0.09	-0.04±0.11	-0.04±0.13	-0.01±0.12	0.03±0.12	-0.04±0.11	0±0.07	-0.02±0.05	0.01±0.1	0.03±0.08	0±0.09
VLF..ms.2..F FT.	43.63±197. 63	101.11±117. 6	19.34±178. 15	15.67±67. 26	- 23.21±174. 93	- 53.65±126. 13	140.75±297 .73	74.27±283. 57	65.99±188. 38	- 64.6±145.7 5	- 28.18±82. 42	- 18.68±38. 73
VLF..ms.2..A R.	199.12±833 .21	406.82±552	147.62±708 .53	26.62±205 .46	- 111.28±59 9.18	- 198.12±48 8.06	240.41±572 .38	142.26±660 .91	70.66±85.8	- 105.94±307 .6	- 59.57±157 .69	- 13.12±110 .14
LF..ms.2..FFT .	877.87±587 3.07	3160.8±4997 .92	1170.91±55 79.27	500.99±14 09.1	- 105.77±39 79.3	- 1230.94±2 562.32	1556.48±48 79.93	1123.44±41 76.28	338.99±11 23.43	- 451.54±122 3.37	- 306.43±83 6.68	- 119.3±780 .98
LF..ms.2..AR.	1264.9±578 0.26	3593.48±527 1.74	1960.99±59 92.32	382.77±14 78.62	- 71.82±369 1.49	- 1017.08±2 455.3	1738.06±48 47.61	1595.87±50 10.34	641.89±10 00.97	- 235.63±126 6.05	- 156.81±59 8.67	- 70.27±659 .1
HF..ms.2..FF T.	3977.9±139 50.34	7814.47±151 41.85	4361.12±16 171.07	139.31±22 71.2	- 1494.26±3 601.48	- 1201.62±4 576.05	2564.07±88 17.67	1525.68±16 053.38	282.69±10 06.41	- 4792.4±165 42.89	119.3±240 0.34	24.69±711 .14

HF..ms.2..AR.	4463.08±14 100.6	7741.14±135 09.72	4041.64±14 520.01	- 84.98±232 3.08	- 2077.73±4 030.26	- 1520.56±5 329.64	3168.47±10 106.6	61±15572.0 4	439.79±87 9.32	- 3604.15±14 111.46	111.81±24 28.67	- 48.82±100 6.06
VLF..log..FFT.	0.87±2.42	1.33±1.98	0.49±2.07	0.17±2.04	-0.47±2.29	-0.52±1.59	1.61±1.53	1.03±1.67	0.96±1.34	-0.49±1.71	-0.56±1.79	-0.53±1.2
VLF..log..AR.	1.12±2.58	1.45±2.5	0.51±1.92	0.06±2.45	-0.7±2.3	-0.66±2.16	1.39±1.11	0.91±2.19	0.93±1.35	-0.27±1.78	-0.49±1.56	-0.21±1.77
LF..log..FFT.	1.27±3.17	1.95±2.75	0.7±2.56	0.43±3.22	-0.65±2.81	-0.87±2.61	1.47±1.55	1.28±2.19	1.46±1.67	0.13±1.68	0.12±1.02	-0.22±1.91
LF..log..AR.	1.35±3.24	1.83±2.48	0.75±2.23	0.19±2.93	-0.65±2.78	-0.74±2.41	1.52±1.2	1.21±2.8	1.36±2.02	0.01±2.21	0.03±0.96	-0.14±2.43
HF..log..FFT.	1.12±3.46	1.41±3.13	0.56±2.89	0.11±3	-0.54±2.65	-0.34±2.23	1.44±1.76	0.71±2.35	1.16±1.84	-0.43±2.6	-0.02±1.6	0.26±2.27
HF..log..AR.	1.02±3.47	1.36±2.89	0.19±2.14	0.18±2.92	-0.79±2.79	-0.66±2.29	1.51±1.58	0.87±2.56	1.06±2	-0.42±2.85	-0.03±1.57	-0.02±2.41
VLF.....FFT.	-1.5±14.14	-0.48±9.83	-0.91±10.94	1.05±13.0 2	0.35±10.93	-2.08±8.56	-2.7±10.21	-0.64±12.38	- 4.11±12.96	- 0.16±15.07	- 2.51±16.0 6	- 4.04±10.4 6
VLF.....AR.	0.62±11.34	-0.36±11.16	1.47±7.57	-1.2±10.44	0.26±10.09	0.63±8.75	-3.97±9.39	-1.28±9.01	- 4.77±13.68	- 2.21±13.93	- 3.17±20.9 3	- -2.22±8.54
LF.....FFT.	4.36±20.87	10.72±24.36	3.95±22.57	4.96±23.6 1	- 1.99±29.16	- 8.53±18.27	3.41±27.12	11.39±24.0 3	8.98±19.17	9.76±23.53	3.81±25.8	- 6.29±15.7 5
LF.....AR.	5.68±18.98	9.28±24.96	10.37±22.4 4	1.49±23.8 8	3.23±31.11	- 1.46±23.46	4.05±24.45	7.67±23.51	8.89±21.23	5.3±21.48	1.29±21.6 3	- 1.58±13.7 9
HF.....FFT.	-2.72±27.07	-9.94±31.43	-2.82±27.92	-5.87±29.9	1.69±34.64	10.56±18.7 3	-0.58±32.13	- 10.48±31.3 3	- 4.76±28.28	- -9.42±36.24	- 1.29±38.9 1	10.11±22. 27
HF.....AR.	-6.13±25.3	-8.58±33.67	- 11.63±26.6 3	- 0.17±30.8 8	- 3.41±39.01	0.83±29.01	-0.02±31.31	-6.33±27.65	- 4.02±27.92	- -7.48±32.85	1.82±40.1 6	3.75±18.7
LF..n.u...FFT.	3.5±25.77	11.26±30.51	3.68±27.46	6.42±28.2 1	- 1.84±34.32	- 10.65±18.3 4	1.2±31.44	11.09±30	6.56±26.14	10.7±33.62	3.44±35.9 8	- 8.81±20.0 1
LF..n.u...AR.	6.42±24.57	9.68±32.95	12.24±26.4 1	1.02±30.3 4	3.94±39.1	- 1.06±29.39	0.71±30.49	7.27±28.46	5.71±28.46	8.16±31.03	0.59±35.9 2	- 3.15±18.3 8
HF..n.u...FFT.	-3.36±25.63	-10.92±30.39	-3.45±27.3	- 6.26±28.1 1	1.9±34.1	10.6±18.18	-1.07±31.11	- 10.81±29.6 2	- 6.44±25.95	- 10.51±33.3 7	- 3.43±35.3 5	8.6±19.71
HF..n.u...AR.	-6.24±24.32	-9.3±32.89	-12.02±26.2	- 0.87±30.3 3	-3.85±38.7	1.06±29.04	-0.64±30.23	-7.2±28.23	-5.6±28.35	-8.13±30.87	- 0.64±35.5 8	3.11±18.2 4
To- tal.power..ms. 2..FFT.	4906.31±19 555.87	11085.92±20 081.97	5546.01±21 348.24	375.21±35 32.69	- 1635.28±7 319.38	- 2493.84±6 823.85	4271.37±13 831.21	336.86±194 51.73	694.09±21 05.22	5330.88±17 433.03	217.03±28 51.4	107.62±14 50.89

To- tal.power..ms. 2..AR.	5943.88±20 373.8	11762.34±19 028.78	6158.46±20 785.94	322.69±38 49.54	- 2278.65±7 592.45	- 2739.42±7 914.85	5158.46±15 452.05	1799.16±20 536.25	1153.94±1 732.97	- 3958.44±15 517.15	- 106.2±297 9.45	- 131.73±16 73.05
LF.HF.ra- tio.FFT.	-0.38±3.15	-2.25±11.82	0.06±1.94	-2.03±9.27	0.31±1.98	2.27±10.48	-0.3±1.84	0.37±1.4	0.26±1.36	0.75±2.04	0.66±1.88	-0.25±0.87
LF.HF.ra- tio.AR.	0.1±1.65	-1.4±7.85	0.56±1.08	-1.64±7.1	0.39±2	1.83±8.16	-0.37±2.04	0.35±1.52	0.28±1.65	0.78±2.1	0.64±1.99	-0.06±0.97

01 means difference between one day before surgery and 1 day after surgery. 02 means difference between one day before surgery and 2 day after surgery, 03 means difference between one day before surgery and 3 day after surgery, 12 means difference between 1 day after surgery and 2 day after surgery, 13 means difference between 1 day after surgery and 3 day after surgery and 23 means difference between 2 day after surgery and 3 day after surgery. Significant differences between different measurement days were not found.

Results of interventions for surgery group PR including all HRV parameters:

Parameters	Mean \pm SD					
	A			B		
	01	02	12	01	02	12
PNS.index	0.4 \pm 1.09	0.22 \pm 1.51	-0.14 \pm 1.01	-0.03 \pm 2.32	0.29 \pm 2.24	0.42 \pm 1.79
SNS.index	-0.76 \pm 2.62	-1.1 \pm 2.79	-0.46 \pm 3.36	-1.27 \pm 3.01	-1.54 \pm 2.12	-0.41 \pm 2.04
Stress.index	-4.42 \pm 16.25	-6 \pm 14.8	-2.4 \pm 21.49	-8.14 \pm 13.89	-7.69 \pm 11.05	-0.1 \pm 10.84
Mean.RR...ms.	28.61 \pm 123.64	51.51 \pm 124.1	18.82 \pm 68.13	26.44 \pm 157.36	68.08 \pm 121.42	55.87 \pm 93.87
STD.RR..ms.	10 \pm 19.35	5.58 \pm 21.14	-3.85 \pm 22.72	2.37 \pm 36.14	-0.95 \pm 52.81	-2.16 \pm 51.91
Mean.HR..beats.min.	-1.56 \pm 8.65	-4.03 \pm 9.2	-1.8 \pm 5.27	-2.2 \pm 13.23	-5.37 \pm 10.24	-4.12 \pm 8.84
STD.HR..beats.min.	1.02 \pm 2.08	0.58 \pm 2	-0.26 \pm 1.91	0.11 \pm 2.65	-1.69 \pm 8.37	-1.8 \pm 8.29
Min.HR..beats.min.	-3.71 \pm 11.26	-4.95 \pm 10.52	-1.58 \pm 8.42	-3.38 \pm 14.71	-5.92 \pm 8.61	-3.26 \pm 8.08
Max.HR..beats.min.	0.96 \pm 12.92	-0.28 \pm 12.02	-0.57 \pm 7.61	0.67 \pm 14.15	-5.46 \pm 22.35	-7.11 \pm 20.72
RMSSD..ms.	11.05 \pm 27.4	2.94 \pm 38.36	-7.59 \pm 38.23	-1.03 \pm 54.96	-0.94 \pm 68.31	1.47 \pm 65.5
NNxx..beats.	10.53 \pm 56.69	-1.89 \pm 158.2	-13.5 \pm 169.31	-5.79 \pm 127.64	-31.74 \pm 187.77	-23.83 \pm 140.48
pNNxx....	2.54 \pm 10.74	1.2 \pm 23.39	-1.73 \pm 24.09	-0.72 \pm 20.24	-2.7 \pm 22.24	-1.39 \pm 16.96
RR.tri.index	0.84 \pm 2.71	1.71 \pm 2.26	0.73 \pm 2.48	1.59 \pm 4.92	0.48 \pm 7.32	-1.05 \pm 4.8
TINN..ms.	45.53 \pm 253.99	29.21 \pm 216.92	0.72 \pm 303.89	37.26 \pm 366.48	98.95 \pm 271.29	92.33 \pm 314.54
SD1..ms.	7.82 \pm 19.39	2.08 \pm 27.15	-5.37 \pm 27.05	-0.73 \pm 38.89	-0.66 \pm 48.33	1.05 \pm 46.35
SD2..ms.	11.15 \pm 20.33	9.2 \pm 17.58	-1.04 \pm 18.94	5.37 \pm 34.72	-1.37 \pm 58.06	-5.4 \pm 58.16
SD2.SD1.ratio	0.21 \pm 0.55	0.04 \pm 0.75	-0.23 \pm 0.7	0.05 \pm 0.78	-0.24 \pm 1.16	-0.3 \pm 0.83
Approximate.en- tropy..ApEn.	-0.08 \pm 0.38	0.13 \pm 0.43	0.19 \pm 0.49	0.03 \pm 0.34	-0.05 \pm 0.31	-0.08 \pm 0.48
Sample.en- tropy..SampEn.	-0.09 \pm 0.62	0.2 \pm 0.64	0.23 \pm 0.77	0.01 \pm 0.47	-0.1 \pm 0.5	-0.12 \pm 0.73
alpha.1	0.1 \pm 0.28	0.06 \pm 0.36	-0.03 \pm 0.33	0.08 \pm 0.37	-0.03 \pm 0.42	-0.12 \pm 0.32
alpha.2	0 \pm 0.15	0.01 \pm 0.19	-0.01 \pm 0.16	-0.03 \pm 0.26	-0.07 \pm 0.2	-0.03 \pm 0.17

VLF..Hz..FFT.	0±0.01	0±0.01	0±0.01	0±0.01	0±0.01	0±0
VLF..Hz..AR.	0±0.01	0±0.02	0.01±0.01	0±0.01	0.01±0.02	0.01±0.02
LF..Hz..FFT.	0±0.02	0±0.03	0±0.03	0±0.05	0.01±0.04	0.02±0.04
LF..Hz..AR.	0±0.03	0±0.04	0±0.05	0±0.05	0.01±0.04	0.01±0.04
HF..Hz..FFT.	0.03±0.1	0.02±0.09	-0.02±0.12	-0.01±0.08	0.01±0.08	0.02±0.08
HF..Hz..AR.	-0.01±0.11	0.02±0.1	0.01±0.14	0±0.1	0.02±0.06	0.03±0.08
VLF..ms.2..FFT.	33.61±144.47	56.83±83.68	25.72±110.91	-13.94±194.08	-9.65±151.51	20.44±156.64
VLF..ms.2..AR.	67.98±155.09	61.91±108.36	-1.89±111.7	-69.21±334.14	-63.87±324.96	17.63±328.03
LF..ms.2..FFT.	195.82±757.17	237.77±718.58	53.48±574.02	-275.91±1633.77	24.67±1365.27	430.65±2158.34
LF..ms.2..AR.	259.05±528.16	154.39±586.3	-82.9±512.48	33.35±1287.84	146.31±1450.27	214.18±1682.69
HF..ms.2..FFT.	433.1±968.83	246.42±1069.22	-84.67±588.44	-418±1741.89	-883.74±3334.81	-377.76±3596.31
HF..ms.2..AR.	423.43±912.41	221.89±1253.82	-144.38±689.98	-189.22±1937.61	-742.17±3530.66	-537.4±3841.53
VLF..log..FFT.	0.89±2.27	0.83±1.55	-0.1±2.06	0.58±1.94	0.23±1.88	-0.16±1.67
VLF..log..AR.	0.94±2	0.72±1.45	-0.18±2.11	0.55±2.03	0.31±1.97	-0.16±2.05
LF..log..FFT.	0.81±2.36	0.74±1.66	0.01±2.67	0.72±2.33	0.63±2.39	0.04±2.28
LF..log..AR.	0.91±2.09	0.7±1.7	-0.14±2.48	0.96±2.19	0.96±2.36	0.07±2.43
HF..log..FFT.	0.74±1.91	0.6±1.87	0.01±2.51	0.38±2.78	0.71±3.02	0.47±2.55
HF..log..AR.	0.66±1.84	0.54±1.97	0.02±2.46	0.73±2.86	1.03±3.03	0.37±2.62
VLF.....FFT.	1.47±10.21	1.25±11.64	-1.29±7.86	-1.49±12.22	-5.14±12.52	-2.2±10.56
VLF.....AR.	1.59±8.05	1.47±8.96	-0.7±7.07	-2.2±10.4	-6.8±11.6	-3.85±8.53
LF.....FFT.	0.76±19.51	3.04±22.24	1.14±12.45	7.2±17.27	3.42±21.76	-4.73±17.2
LF.....AR.	3.72±16.98	3.41±19.37	-1.49±11.45	4.75±17.32	4.13±20.4	-0.78±15.05

HF.....FFT.	-2.25±23.86	-4.25±26.23	0.22±13.81	-5.61±24.36	1.68±29.28	6.79±20.08
HF.....AR.	-5.23±20.92	-4.82±26.13	2.17±12.59	-2.53±25.03	2.66±28.92	4.56±19.04
LF..n.u...FFT.	1.26±24.35	4.19±25.64	1.09±13.75	6.31±22.31	-0.7±28.94	-6.9±19.63
LF..n.u...AR.	4.93±22.06	4.46±26.08	-2.13±12.49	3.6±23.15	-0.22±28.52	-3.62±18.97
HF..n.u...FFT.	-1.29±24.17	-4.16±25.4	-1.02±13.57	-6.2±22.12	0.66±28.81	6.76±19.48
HF..n.u...AR.	-4.85±22	-4.41±25.91	2.11±12.23	-3.58±23.02	0.23±28.45	3.56±18.82
To- tal.power..ms.2..FFT .	666.89±1667. 1	543.39±1711.7 8	- -8.3±1205.48	- 711.63±3419.5 5	- 874.78±4693.0 9	- 71.13±5627.49
To- tal.power..ms.2..AR.	752.68±1439. 3	440.53±1838.0 8	- 229.53±1279.0 5	- -226.1±3339.23 3	- 666.74±5064.6 3	- -311.7±5712.39
LF.HF.ratio.FFT.	0.01±3.95	-0.57±5.3	-0.7±2.23	-0.54±4.22	-0.92±3.93	-0.4±4.38
LF.HF.ratio.AR.	0.59±2.49	-0.29±3.78	-1±2.93	-0.5±2.67	-1.11±4.03	-0.68±3.67

01 means difference between one day before surgery and 1 day after surgery. 02 means difference between one day before surgery and 2 day after surgery, 03 means difference between one day before surgery and 3 day after surgery, 12 means difference between 1 day after surgery and 2 day after surgery, 13 means difference between 1 day after surgery and 3 day after surgery and 23 means difference between 2 day after surgery and 3 day after surgery. Significant differences between different measurement days were not found.

Results of interventions for surgery group PM including all HRV parameters:

Parameters	Mean \pm SD					
	A			B		
	01	02	12	01	02	12
PNS.index	0.18 \pm 1.85 ^a	0.16 \pm 1.69	0.01 \pm 2.06	-0.92 \pm 1.64	-0.1 \pm 1.63	0.59 \pm 1.71
SNS.index	-0.43 \pm 1.68 ^a	-1.08 \pm 2.08	-0.72 \pm 2.41	0.67 \pm 1.54	-0.04 \pm 2.13	-0.58 \pm 1.37
Stress.index	-3.97 \pm 6.77 ^a	-5.61 \pm 11.19	-1.78 \pm 13.62	1.46 \pm 7.82	-1.02 \pm 10.32	-1.7 \pm 6.58
Mean.RR...ms.	-17.94 \pm 99.13	49.92 \pm 120.45	76.44 \pm 106.58	-32.65 \pm 141.7	6.44 \pm 136.05	32.99 \pm 97.58
STD.RR..ms.	11.07 \pm 31.18 ^a	1.7 \pm 39.98	-9.65 \pm 41.01	-11.22 \pm 33.76	-0.99 \pm 27.78	5.34 \pm 37.26
Mean.HR..beats.min.	1.45 \pm 8	-4.3 \pm 10.01	-6.38 \pm 10.11	3.35 \pm 11.42	0.11 \pm 10.22	-2.93 \pm 7.42
STD.HR..beats.min.	1.51 \pm 3.41 ^a	-0.16 \pm 4.25	-1.73 \pm 4.44	-1.19 \pm 4.54	-0.41 \pm 1.82	0.71 \pm 4.93
Min.HR..beats.min.	-0.94 \pm 8.2	-5.3 \pm 10.64	-4.85 \pm 9.31	2.51 \pm 10.66	-0.12 \pm 10.57	-1.68 \pm 7.81
Max.HR..beats.min.	5.44 \pm 14.06	-2.32 \pm 16.02	-8.49 \pm 18.65	0.11 \pm 19.23	-0.15 \pm 11.75	-0.55 \pm 17.21
RMSSD..ms.	13.42 \pm 49.16 ^a	-0.43 \pm 51.03	-13.98 \pm 59.33	-20.11 \pm 57.1	-0.69 \pm 44.14	11.61 \pm 60.7
NNxx..beats.	17.6 \pm 78.92	-47.95 \pm 170.33	-68.05 \pm 187.39	-14.77 \pm 120.06	9.73 \pm 33.77	38.6 \pm 116.29
pNNxx....	1.91 \pm 9.95	-5.43 \pm 18.93	-7.62 \pm 20.5	-2.18 \pm 16.63	1.32 \pm 5.77	5.56 \pm 15.68
RR.tri.index	-0.02 \pm 1.7	-1.82 \pm 8.01	-2 \pm 8.19	-0.38 \pm 2.33	0.35 \pm 2.22	0.75 \pm 1.87
TINN..ms.	123.75 \pm 198.96 ^a	100.24 \pm 343.8	-20.6 \pm 282.55	-27.41 \pm 247.36	-23.55 \pm 321.54	-21.25 \pm 269.2
SD1..ms.	9.49 \pm 34.79 ^a	-0.3 \pm 36.11	-9.89 \pm 41.98	-14.24 \pm 40.41	-0.49 \pm 31.24	8.22 \pm 42.95
SD2..ms.	11.86 \pm 27.89	2.67 \pm 44.96	-9.6 \pm 41.66	-8.01 \pm 27.17	-1.2 \pm 25.16	2.67 \pm 32.02
SD2.SD1.ratio	0.11 \pm 0.5	-0.03 \pm 0.52	-0.17 \pm 0.68	0.2 \pm 0.49	-0.04 \pm 0.87	-0.22 \pm 0.86
Approximate.entropy..ApEn.	-0.1 \pm 0.27	-0.12 \pm 0.43	-0.03 \pm 0.46	0.06 \pm 0.31	0.06 \pm 0.38	0.03 \pm 0.37
Sample.entropy..SampEn.	-0.19 \pm 0.41	-0.2 \pm 0.68	-0.02 \pm 0.73	0.09 \pm 0.53	0.12 \pm 0.61	0.08 \pm 0.6
alpha.1	0.12 \pm 0.21	0.03 \pm 0.19	-0.09 \pm 0.29	0.13 \pm 0.29	0 \pm 0.35	-0.12 \pm 0.33

alpha.2	0±0.16	-0.06±0.15	-0.06±0.22	-0.01±0.17	-0.03±0.14	-0.04±0.14
VLF..Hz..FFT.	0±0.01	0±0.01	0±0.01	0±0	0±0.01	0±0.01
VLF..Hz..AR.	0±0.02	0.01±0.02	0.01±0.01	0±0.02	0.01±0.02	0±0.02
LF..Hz..FFT.	0.01±0.04	0.01±0.04	0±0.02	0.01±0.03	0±0.04	-0.01±0.04
LF..Hz..AR.	0±0.05	0.01±0.04	0.01±0.05	0±0.05	0.01±0.04	0.02±0.05
HF..Hz..FFT.	0±0.06	-0.01±0.07	-0.01±0.06	0.02±0.09	0±0.06	-0.02±0.07
HF..Hz..AR.	-0.01±0.06	-0.01±0.1	0.01±0.08	0±0.08	-0.01±0.07	-0.01±0.08
VLF..ms.2..FFT.	39.62±127.26	20.68±154.84	-16.38±149.27	7.06±67.45	94.48±271.7	32.73±172.34
VLF..ms.2..AR.	66.75±169.25	-53.32±457.87	-124.71±443.62	-46.25±202.84	-16.02±335.4	-28.15±299.44
LF..ms.2..FFT.	599.69±1234.4	- 187.89±2920.7 3	-805±2536.16	-51.15±1078.45	286.74±2058.6 6	- 168.17±1025.5 8
LF..ms.2..AR.	461.59±898.94	- 175.63±2333.9 9	- 655.97±2109.62	- 563.27±3005.16	- 144.01±2330.7 1	33.78±2288.96
HF..ms.2..FFT.	414.02±2315.5	- 366.72±3324.6 9	- 801.84±3207.87	- 1579.37±4862.4 6	665.15±5821.6 2	931.89±3741.4 4
HF..ms.2..AR.	331.24±1887.66	- 548.07±3167.8 1	- 909.44±3187.36	- 1411.96±3807.3 5	- 68.37±3911.57	593.85±3019.8 9
VLF..log..FFT.	0.53±1.54	0.47±1.95	0±1.76	-0.02±1	0.41±1.16	0.16±0.95
VLF..log..AR.	0.57±1.34 ^a	0.48±2.02	-0.09±1.91	-0.24±0.97	0.15±1.11	0.24±1.12
LF..log..FFT.	0.79±1.46 ^a	0.83±2.3	0.05±2.25	0.13±1.37	0.2±1.43	-0.19±1.25
LF..log..AR.	0.77±1.35	0.89±2.14	0.1±2.09	0.04±1.3	0.26±1.29	0.01±1.28
HF..log..FFT.	0.52±2.42	0.7±2.55	0.19±2.83	-0.45±1.54	0.02±1.72	0.26±1.43
HF..log..AR.	0.51±1.87	0.75±2.45	0.25±2.5	-0.51±1.49	0.11±1.59	0.52±1.32
VLF.....FFT.	-0.35±9.34	-3.73±10.68	-3.02±13.53	-0.09±8.99	0.64±6.67	0.78±7.1
VLF.....AR.	-0.42±8.03	-3.3±7.78	-2.95±9.75	-0.81±8.09	-0.11±5.45	0.75±7.36

LF.....FFT.	4.96±21.66	5.74±15.04	0.48±23.04	11.19±17.87	4.73±21.22	-7.28±22.54
LF.....AR.	5.39±18.34	5.75±14.97	-0.07±19.02	10.58±16.77	3.96±19.38	-8.21±21.19
HF.....FFT.	-4.61±25.16	-2±18.1	2.56±29.79	-10.94±21.98	-5.3±22.37	6.42±24.85
HF.....AR.	-4.97±20.09	-2.46±18.17	3.01±25.11	-9.7±20.18	-3.75±20.49	7.51±22.98
LF..n.u....FFT.	4.87±25.66	2.65±17.1	-2.37±29.28	11.92±21.39	5.55±22.84	-6.83±25.13
LF..n.u....AR.	5.56±21.16	3.44±18.78	-2.74±25.17	11.26±20.43	4.51±22.24	-8.19±24.5
HF..n.u....FFT.	-4.87±25.51	-2.62±17.05	2.39±29.17	-11.76±21.32	-5.47±22.77	6.75±25.01
HF..n.u....AR.	-5.56±21.06	-3.45±18.7	2.73±25.08	-11.18±20.31	-4.39±22.08	8.23±24.29
To- tal.power..ms.2..FF T.	1049.18±3512.0 9	- 538.09±6305.7 1	- 1623.45±5617.7 8	- 1635.71±5792.6 9	1043±7963.37	801.96±4582.6
To- tal.power..ms.2..AR.	859.74±2784.07	- 778.74±5909.8 3	- 1692.07±5535.6 5	- 2027.09±6618.3 4	- 228.45±6485.4	604.28±4890.0 4
LF.HF.ratio.FFT.	0.44±2.79	0.28±1.53	-0.16±2.68	0.8±2.37	-1.03±6.02	-1.56±6.1
LF.HF.ratio.AR.	0.22±1.79	-0.17±1.78	-0.44±2.38	0.53±1.38	-1.05±5.79	-1.62±5.95

01 means difference between one day before surgery and 1 day after surgery. 02 means difference between one day before surgery and 2 day after surgery, 03 means difference between one day before surgery and 3 day after surgery, 12 means difference between 1 day after surgery and 2 day after surgery, 13 means difference between 1 day after surgery and 3 day after surgery and 23 means difference between 2 day after surgery and 3 day after surgery. Significant differences between PREOP and 1POP: ^a*P* < 0.05. Significant differences between other measurement days were not found.

APPENDIX B: RESULTS OF ALL GROUPS

Results for all groups including all HRV parameters:

Parameters	Mean \pm SD			
	PREOP	1POP	2POP	3POP
PNS.index	0.81 \pm 2.66	0.82 \pm 4.88	0.27 \pm 2.35	0.85 \pm 2.59
SNS.index	0.41 \pm 1.75 ^{ab}	1.1 \pm 2.35	1.44 \pm 2.37	1.11 \pm 2.27
Stress.index	11.5 \pm 7.81 ^{ab}	15.83 \pm 11.32	16.59 \pm 12.06	12.75 \pm 10.49
Mean.RR...ms.	919.45 \pm 156.29 ^{bc}	899.29 \pm 179.65 ^{de}	846.8 \pm 134.36	799.04 \pm 182.11
STD.RR..ms.	50.58 \pm 53.02	46.95 \pm 96.74	40.79 \pm 47.96	56.7 \pm 53.67
Mean.HR..beat s.min.	67.19 \pm 11.79 ^b _c	69.02 \pm 12.77 ^d _e	72.65 \pm 11.71	78.35 \pm 15.6
STD.HR..beats .min.	3.97 \pm 4.3	4.01 \pm 8.21	3.89 \pm 5.11	6.55 \pm 8.02
Min.HR..beats. min.	59.18 \pm 10.93 ^b _c	62.55 \pm 11.71 ^d	65.24 \pm 11.41	67.77 \pm 13
Max.HR..beats. min.	78.19 \pm 14.39 ^b _c	78.37 \pm 16.37	82.17 \pm 15.44	89.95 \pm 23.03
RMSSD..ms.	66.58 \pm 82.72	66.97 \pm 159.41	54.95 \pm 72.9	80.75 \pm 79.05
NNxx..beats.	87.3 \pm 147.98	68.14 \pm 165.84	77.34 \pm 165.05	155.09 \pm 248.35
pNNxx....	13.6 \pm 22.14	10.1 \pm 21.59	10.73 \pm 21.79	18.85 \pm 27.41
RR.tri.index	8.12 \pm 7.54 ^a	6.45 \pm 8.23	6.32 \pm 6.96	8.16 \pm 8.99
TINN..ms.	381.93 \pm 327.98	339.42 \pm 472	296.88 \pm 278.76	415.97 \pm 300.08
SD1..ms.	47.12 \pm 58.54	47.4 \pm 112.9	38.88 \pm 51.58	57.14 \pm 55.94
SD2..ms.	52.15 \pm 48.72 ^a	44.57 \pm 78.63	41.14 \pm 45.43	55.53 \pm 51.97
SD2.SD1.ratio	1.52 \pm 0.68	1.4 \pm 0.67	1.56 \pm 0.87	1.2 \pm 0.59
Approximate.en- tropy..ApEn.	1.19 \pm 0.3	1.17 \pm 0.35	1.16 \pm 0.39	1.1 \pm 0.45
Sample.en- tropy..SampEn.	1.39 \pm 0.51	1.35 \pm 0.55	1.32 \pm 0.58	1.19 \pm 0.62
alpha.1	0.87 \pm 0.32 ^a	0.78 \pm 0.34	0.85 \pm 0.38	0.68 \pm 0.28
alpha.2	0.36 \pm 0.15 ^b	0.39 \pm 0.19	0.42 \pm 0.18	0.37 \pm 0.22
VLF..Hz..FFT.	0.04 \pm 0	0.04 \pm 0	0.04 \pm 0	0.04 \pm 0
VLF..Hz..AR.	0.04 \pm 0.01 ^b	0.04 \pm 0.01	0.03 \pm 0.02	0.03 \pm 0.01
LF..Hz..FFT.	0.08 \pm 0.03	0.07 \pm 0.03	0.07 \pm 0.03	0.08 \pm 0.04
LF..Hz..AR.	0.09 \pm 0.03	0.1 \pm 0.04	0.09 \pm 0.04	0.11 \pm 0.04
HF..Hz..FFT.	0.24 \pm 0.07 ^c	0.24 \pm 0.07	0.25 \pm 0.07	0.27 \pm 0.08
HF..Hz..AR.	0.23 \pm 0.08	0.24 \pm 0.08	0.24 \pm 0.08	0.24 \pm 0.09

VLF..ms.2..FFT.	111.58±192.97 ^b	462.93±4142.91	58.92±104.05	76.91±107.79
VLF..ms.2..AR.	229.91±434.86	754.75±6385.82	169.87±396.53	228.47±349.86
LF..ms.2..FFT.	1522.38±3612.51	4414.9±36436.45	904.43±2526.22	1355.11±2158.97
LF..ms.2..AR.	1572.2±3614.95	4021.29±32581.26	901.83±2475.53	1282.6±1945.98
HF..ms.2..FFT.	2886.01±8405.42	4132.1±26242.56	2080.38±6984.29	2901.48±4879.22
HF..ms.2..AR.	2948.16±8155.79	3896.6±23835.32	2082.77±6430.79	3214.68±5252.32
VLF..log..FFT.	3.81±1.42 ^{ab}	3.19±1.66	3.13±1.43	3.19±1.69
VLF..log..AR.	4.42±1.46 ^{ab}	3.77±1.74	3.78±1.65	4.1±1.83
LF..log..FFT.	5.86±1.71 ^{ab}	5.1±2.04	4.96±1.99	5.16±2.42
LF..log..AR.	5.96±1.71 ^{ab}	5.09±2.01	5.01±1.95	5.42±2.24
HF..log..FFT.	5.83±2.04	5.29±2.29	5.12±2.4	5.57±2.85
HF..log..AR.	5.99±2.02 ^b	5.38±2.25	5.19±2.37	6.05±2.6
VLF.....FFT.	8.2±6.76	9±9.1	9.68±9.52	8.93±9.99
VLF.....AR.	10.54±6.61	11.52±8.12	12.44±8.33	10.43±10.01
LF.....FFT.	45.66±18.26 ^a _b	40.59±19.38	39.9±20.11	35.75±15.22
LF.....AR.	43.39±17.28 ^a _{bc}	37.94±18.5	38.48±19.33	31.46±14.28
HF.....FFT.	45.95±21.9	50.14±24.48	50.13±25.36	54.94±21.64
HF.....AR.	45.85±20.96	50.27±23.75	48.8±24.44	57.76±20.56
LF..n.u...FFT.	50.67±21.73	46.08±23.9	45.81±25.02 ^f	40.79±20.36
LF..n.u...AR.	49.44±21.19	44.36±23.48	45.47±24.86	36.6±19.5
HF..n.u...FFT.	49.12±21.59	53.63±23.7	53.88±24.82 ^f	58.81±20.15
HF..n.u...AR.	50.33±21.03	55.35±23.3	54.21±24.69	63.02±19.33
To-tal.power..ms.2..FFT.	4528.37±11903.92	9020.16±66677.46	3054.05±8956.33	4351.8±6829.3
To-tal.power..ms.2..AR.	4761.66±12076.82	8682.45±62698.85	3163.79±8792.19	4743.24±7173.44
LF.HF.ra-tio.FFT.	1.79±2.19	1.8±3.18	2.43±5.73	1.1±1.44
LF.HF.ratio.AR.	1.58±1.72	1.5±2.25	2.22±4.49	0.84±0.96

Significant differences between PREOP and 1POP: ^a*P* < 0.01. Significant differences between PREOP and 2POP: ^b*P* < 0.01. Significant differences between PREOP and 3POP: ^c*P* < 0.01. Significant differences between 1POP and 2POP: ^d*P* < 0.01. Significant differences between 1POP and 3POP: ^e*P* < 0.01. Significant differences between 2POP and 3POP: ^f*P* < 0.01.

APPENDIX D: RESULTS OF DIFFERENT GROUPS

Results for surgery group C including all HRV parameters:

Parameters	Mean \pm SD			
	PREOP	1POP	2POP	3POP
PNS.index	2.04 \pm 3.45	0.67 \pm 2.63	0.8 \pm 2.79	0.79 \pm 2.65
SNS.index	-0.22 \pm 1.72 ^{bc}	1.16 \pm 2.61	1.1 \pm 2.44	1.23 \pm 2.32
Stress.index	9.55 \pm 8.06	15.6 \pm 12.29	14.83 \pm 12	13.31 \pm 10.78
Mean.RR...ms.	965.88 \pm 160.5 ^{3abc}	867.87 \pm 166.54	815.38 \pm 124.6	797.55 \pm 185.8
STD.RR...ms.	73.11 \pm 73.69	43.05 \pm 48.43	48.42 \pm 55.72	56.08 \pm 54.17
Mean.HR..beat s.min.	63.83 \pm 10.74 ^{b_c}	71.72 \pm 14.58	75.33 \pm 11.93	78.61 \pm 15.91
STD.HR..beats .min.	5.24 \pm 5.24	4.08 \pm 7.01	4.83 \pm 5.08	6.55 \pm 8.22
Min.HR..beats. min.	55.43 \pm 10.98 ^{a_{bc}}	64.59 \pm 12.59	66.67 \pm 12.69	67.94 \pm 13.12
Max.HR..beats. min.	75.04 \pm 12.74 ^{b_c}	80.22 \pm 19.11	85.24 \pm 14.14	89.72 \pm 23.45
RMSSD..ms.	100.93 \pm 114.7 ³	63.9 \pm 79.18	70.97 \pm 89.51	79.65 \pm 80.02
NNxx..beats.	131.43 \pm 175.6	76 \pm 220.09	83.94 \pm 156.28	149.94 \pm 244.02
pNNxx....	21.43 \pm 28.34	10.03 \pm 23.77	11.5 \pm 20.33	18.15 \pm 26.41
RR.tri.index	10.92 \pm 10.15 ^b	5.18 \pm 7.96	5.51 \pm 6.23	7.64 \pm 8.44
TINN..ms.	499.22 \pm 406.1 ²	362.13 \pm 315.64	362.06 \pm 274.4	411.13 \pm 311.6
SD1..ms.	71.43 \pm 81.2	45.22 \pm 56.04	50.22 \pm 63.34	56.36 \pm 56.63
SD2..ms.	73.03 \pm 67.24 ^a	38.78 \pm 41.34	45.69 \pm 47.83	54.99 \pm 52.28
SD2.SD1.ratio	1.33 \pm 0.59	1.23 \pm 0.67	1.24 \pm 0.73	1.23 \pm 0.61
Approximate.en-tropy..ApEn.	1.14 \pm 0.29	1 \pm 0.42	1.02 \pm 0.43	1.08 \pm 0.46
Sample.en-tropy..SampEn.	1.33 \pm 0.54	1.09 \pm 0.59	1.06 \pm 0.6	1.16 \pm 0.63
alpha.1	0.78 \pm 0.31	0.7 \pm 0.35	0.7 \pm 0.37	0.7 \pm 0.28
alpha.2	0.28 \pm 0.14	0.37 \pm 0.24	0.38 \pm 0.19	0.36 \pm 0.22
VLF..Hz..FFT.	0.04 \pm 0	0.04 \pm 0	0.04 \pm 0	0.04 \pm 0
VLF..Hz..AR.	0.04 \pm 0.01	0.04 \pm 0.01	0.03 \pm 0.01	0.03 \pm 0.01
LF..Hz..FFT.	0.09 \pm 0.04	0.07 \pm 0.03	0.07 \pm 0.03	0.08 \pm 0.04
LF..Hz..AR.	0.1 \pm 0.04	0.11 \pm 0.04	0.1 \pm 0.04	0.11 \pm 0.04
HF..Hz..FFT.	0.21 \pm 0.06 ^{abc}	0.26 \pm 0.08	0.27 \pm 0.07	0.26 \pm 0.08
HF..Hz..AR.	0.21 \pm 0.08 ^b	0.25 \pm 0.09	0.26 \pm 0.09	0.24 \pm 0.09

VLF..ms.2..FFT	129.62±208	48.22±101.93	54.73±111.98	74.61±108.82
VLF..ms.2..AR.	380.27±616.7	143.58±374.22	146.5±268.24	232.4±360.67
LF..ms.2..FFT.	2519.94±4894.49	1105.56±3018.39	689.99±1267.62	1370.81±2212.47
LF..ms.2..AR.	2958.37±5433.56 ^b	1079.2±2756	731.64±1174.03	1294.43±1987
HF..ms.2..FFT.	5928.77±13285.7	1849.6±5047.88	3487.97±10953.27	2905.97±4997.91
HF..ms.2..AR.	6337.8±13147.07	1945.23±5014.57	3206.74±9294.75	3246.19±5392.23
VLF..log..FFT.	3.88±1.54 ^{ab}	2.7±1.53	2.75±1.68	3.1±1.71
VLF..log..AR.	4.79±1.73 ^{ab}	3.46±1.74	3.65±1.85	4.06±1.88
LF..log..FFT.	6.26±2.01 ^{ab}	4.9±2.21	4.67±2.17	5.1±2.47
LF..log..AR.	6.45±2.07 ^{abc}	4.94±2.19	4.98±2.11	5.38±2.29
HF..log..FFT.	6.5±2.29	5.26±2.41	5.48±2.59	5.45±2.91
HF..log..AR.	6.7±2.28	5.38±2.4	5.61±2.51	5.97±2.66
VLF.....FFT.	6.3±6.44	8.31±10.83	6.86±8.31	9.25±10.36
VLF.....AR.	8.81±6.37	10.52±9.78	9.71±7.29	10.7±10.36
LF.....FFT.	41.32±18.32	37.04±18.99	30.16±19.72	36.64±15.58
LF.....AR.	40.14±17.81	34.88±18.6	32.09±18.9	32.03±14.77
HF.....FFT.	52.18±22.19	54.32±25.5	62.51±24.78	53.74±22.21
HF.....AR.	50.83±20.84	54.25±25.26	57.8±23.78	56.93±21.24
LF..n.u...FFT.	45.04±21.47	42.25±24.54	33.75±23.77	42.01±20.85
LF..n.u...AR.	44.77±21	40.9±24.74	36.76±23.41	37.45±20.15
HF..n.u...FFT.	54.75±21.34	57.4±24.37	65.76±23.56	57.61±20.64
HF..n.u...AR.	54.99±20.84	58.73±24.54	62.79±23.32	62.18±19.98
Total.power..ms.2..FFT.	8595.83±18108.94	3010.48±8123.56	4251.3±12073.25	4368.42±6977.84
Total.power..ms.2..AR.	9700.3±19084.88	3174.32±8104.33	4100.37±10512.62	4790.06±7337.63
LF.HF.ra-tio.FFT.	1.22±1.14	1.55±2.46	2.16±8.3	1.17±1.49
LF.HF.ratio.AR.	1.22±1.19	1.34±1.78	1.77±5.48	0.89±0.99

Significant differences between PREOP and 1POP: ^a*P* < 0.01. Significant differences between PREOP and 2POP: ^b*P* < 0.01. Significant differences between PREOP and 3POP: ^c*P* < 0.01. Significant differences between 1POP and 2POP: ^d*P* < 0.01. Significant differences between 1POP and 3POP: ^e*P* < 0.01. Significant differences between 2POP and 3POP: ^f*P* < 0.01.

Results for surgery group PR including all HRV parameters:

Parameters	Mean \pm SD		
	PREOP	1POP	2POP
PNS.index	0.22 \pm 1.63	0.07 \pm 1.65	-0.15 \pm 1.78
SNS.index	0.63 \pm 1.55 ^b	1.6 \pm 2.4	1.97 \pm 2.42
Stress.index	12.25 \pm 7.6 ^b	18.36 \pm 12.92	19.49 \pm 13.49
Mean.RR...ms.	898.59 \pm 150.24 ^b	874.9 \pm 131.5	843.29 \pm 116.42
STD.RR...ms.	38.66 \pm 32.83	32.94 \pm 33.96	33.29 \pm 40.54
Mean.HR..beats.min	68.68 \pm 12.09 ^b	70.3 \pm 12.02	72.63 \pm 11.22
STD.HR..beats.min.	3.45 \pm 4.33	2.96 \pm 4.16	3.41 \pm 6.05
Min.HR..beats.min.	60.78 \pm 10.02 ^b	64.16 \pm 10.91	66.17 \pm 9.67
Max.HR..beats.min.	79.6 \pm 16.59	78.71 \pm 15.51	81.06 \pm 17.09
RMSSD..ms.	48.36 \pm 48.31	43.76 \pm 49.94	43 \pm 56
NNxx..beats.	73.05 \pm 157.84	74.24 \pm 172.03	71.89 \pm 186.84
pNNxx....	10.3 \pm 19.16	9.89 \pm 20.72	9.4 \pm 23.69
RR.tri.index	6.77 \pm 5.09	5.65 \pm 4.84	5.29 \pm 5.76
TINN..ms.	321.13 \pm 238.32	278.53 \pm 269.72	231.55 \pm 225.9
SD1..ms.	34.22 \pm 34.18	30.96 \pm 35.34	30.43 \pm 39.62
SD2..ms.	41.38 \pm 33.09	33.72 \pm 33.7	34.36 \pm 42.68
SD2.SD1.ratio	1.54 \pm 0.71	1.41 \pm 0.7	1.67 \pm 0.93
Approximate.en- tropy..ApEn.	1.23 \pm 0.27	1.25 \pm 0.3	1.18 \pm 0.4
Sample.en- tropy..SampEn.	1.42 \pm 0.47	1.46 \pm 0.5	1.37 \pm 0.59
alpha.1	0.89 \pm 0.3	0.8 \pm 0.36	0.88 \pm 0.39
alpha.2	0.4 \pm 0.14	0.41 \pm 0.17	0.44 \pm 0.17
VLF..Hz..FFT.	0.04 \pm 0.01	0.04 \pm 0	0.04 \pm 0
VLF..Hz..AR.	0.04 \pm 0.01 ^b	0.04 \pm 0.01 ^d	0.03 \pm 0.02
LF..Hz..FFT.	0.07 \pm 0.03	0.07 \pm 0.03	0.06 \pm 0.03
LF..Hz..AR.	0.09 \pm 0.03	0.09 \pm 0.04	0.08 \pm 0.04
HF..Hz..FFT.	0.26 \pm 0.08	0.24 \pm 0.07	0.24 \pm 0.07
HF..Hz..AR.	0.25 \pm 0.07	0.25 \pm 0.08	0.23 \pm 0.08
VLF..ms.2..FFT.	84.59 \pm 98.06	77.95 \pm 145.8	53.6 \pm 89.64
VLF..ms.2..AR.	139.28 \pm 164	140.02 \pm 270.48	124.42 \pm 252.65
LF..ms.2..FFT.	833.42 \pm 1853.15	912.76 \pm 2271.06	621.23 \pm 1431.52
LF..ms.2..AR.	829.6 \pm 1716.06	710.55 \pm 1628.08	600.29 \pm 1314.92
HF..ms.2..FFT.	936.35 \pm 1946.45	973.3 \pm 1802.66	1083.24 \pm 2517.88
HF..ms.2..AR.	1067.53 \pm 2067.33	960.21 \pm 1832.86	1137.21 \pm 2630.61
VLF..log..FFT.	3.69 \pm 1.42	2.99 \pm 1.75	3.07 \pm 1.41
VLF..log..AR.	4.19 \pm 1.38	3.44 \pm 1.82	3.58 \pm 1.62
LF..log..FFT.	5.47 \pm 1.63 ^b	4.76 \pm 2.15	4.67 \pm 1.99
LF..log..AR.	5.61 \pm 1.58 ^b	4.69 \pm 2.04	4.67 \pm 2
HF..log..FFT.	5.39 \pm 1.68	4.88 \pm 2.26	4.58 \pm 2.33

HF..log..AR.	5.59±1.71	4.9±2.18	4.67±2.31
VLF.....FFT.	9.71±7.52	9.52±9.19	11.96±10
VLF.....AR.	11.66±6.97	11.91±7.35	14.61±8.89
LF.....FFT.	45.4±18.32	41.44±20.54	42.57±20.07
LF.....AR.	43.08±17.15	39.07±19.65	39.78±19.4
HF.....FFT.	44.66±21.81	48.76±25.56	45.23±25.41
HF.....AR.	45.02±21.17	48.73±24.56	45.35±25.1
LF..n.u...FFT.	51.18±21.98	47.29±25.17	50.06±25.85
LF..n.u...AR.	49.78±21.51	45.75±24.56	48.35±26.08
HF..n.u...FFT.	48.56±21.83	52.4±24.95	49.69±25.67
HF..n.u...AR.	49.97±21.36	53.93±24.36	51.36±25.92
To- tal.power..ms.2..FF T.	1859.07±3660.7 1	1968.67±4036	1764.18±3810.9 6
To- tal.power..ms.2..AR.	2041.65±3675.0 7	1815.62±3472.6 5	1868.64±4020.5 7
LF.HF.ratio.FFT.	1.96±2.54	2.26±4.55	2.77±4.4
LF.HF.ratio.AR.	1.75±2.18	1.74±2.96	2.51±3.77

Significant differences between PREOP and 1POP: ^a $P < 0.01$. Significant differences between PREOP and 2POP: ^b $P < 0.01$. Significant differences between PREOP and 3POP: ^c $P < 0.01$. Significant differences between 1POP and 2POP: ^d $P < 0.01$. Significant differences between 1POP and 3POP: ^e $P < 0.01$. Significant differences between 2POP and 3POP: ^f $P < 0.01$.

Results for surgery group PM including all HRV parameters:

Parameters	Mean \pm SD		
	PREOP	1POP	2POP
PNS.index	0.32 \pm 2.34	0.56 \pm 2.64	0.25 \pm 2.41
SNS.index	0.73 \pm 1.85	0.67 \pm 1.95	1.23 \pm 2.26
Stress.index	12.44 \pm 7.67	13.82 \pm 8.32	15.32 \pm 10.48
Mean.RR...ms.	899.81 \pm 153.22	915.43 \pm 125.49 ^d	873.29 \pm 152.5
STD.RR...ms.	42.64 \pm 41.38	41.22 \pm 49.9	41.73 \pm 47.94
Mean.HR..beats.min.	68.64 \pm 12.02	66.85 \pm 10.03 ^d	70.67 \pm 11.83
STD.HR..beats.min.	3.4 \pm 3.12	3.32 \pm 4.14	3.62 \pm 4.16
Min.HR..beats.min.	60.85 \pm 11.12	60.74 \pm 9.12	63.36 \pm 11.83
Max.HR..beats.min.	79.54 \pm 13.45	77.66 \pm 14.7	80.87 \pm 14.86
RMSD..ms.	54.53 \pm 67.36	55.12 \pm 80.71	53.59 \pm 71.88
NNxx..beats.	63.67 \pm 102.56	59 \pm 112.05	77.23 \pm 154.28
pNNxx....	10.1 \pm 17.07	9.38 \pm 18.17	11.33 \pm 21.54
RR.tri.index	7 \pm 6.28	6.97 \pm 6.84	7.83 \pm 8.21
TINN..ms.	339.53 \pm 306.19	287.5 \pm 276.12	306.09 \pm 315.43
SD1..ms.	38.59 \pm 47.67	39.01 \pm 57.12	37.92 \pm 50.87
SD2..ms.	44.56 \pm 36.42	41.62 \pm 43.14	43.76 \pm 46.32
SD2.SD1.ratio	1.66 \pm 0.69	1.52 \pm 0.62	1.7 \pm 0.85
Approximate.en- tropy..ApEn.	1.21 \pm 0.32	1.22 \pm 0.31	1.24 \pm 0.32
Sample.en- tropy..SampEn.	1.41 \pm 0.53	1.45 \pm 0.52	1.46 \pm 0.51
alpha.1	0.94 \pm 0.33 ^a	0.83 \pm 0.31	0.93 \pm 0.35
alpha.2	0.38 \pm 0.15	0.39 \pm 0.17	0.42 \pm 0.18
VLF..Hz..FFT.	0.04 \pm 0 ^b	0.04 \pm 0 ^d	0.03 \pm 0
VLF..Hz..AR.	0.04 \pm 0.01	0.03 \pm 0.01	0.03 \pm 0.02
LF..Hz..FFT.	0.08 \pm 0.03	0.06 \pm 0.03	0.07 \pm 0.03
LF..Hz..AR.	0.09 \pm 0.03	0.09 \pm 0.04	0.08 \pm 0.04
HF..Hz..FFT.	0.24 \pm 0.07	0.23 \pm 0.07	0.24 \pm 0.07
HF..Hz..AR.	0.23 \pm 0.08	0.24 \pm 0.07	0.23 \pm 0.08
VLF..ms.2..FFT.	120.73 \pm 239.71	77.71 \pm 193.79	66.75 \pm 111.52
VLF..ms.2..AR.	186.85 \pm 395.79	160.73 \pm 493.97	227.42 \pm 551.62
LF..ms.2..FFT.	1314.57 \pm 3454.18	898.07 \pm 3778.01	1314.26 \pm 3707.73
LF..ms.2..AR.	1092.56 \pm 2611.2	1037.12 \pm 4528.41	1294.97 \pm 3679.52
HF..ms.2..FFT.	2117.22 \pm 5888.08	2211.78 \pm 7643.36	1914.06 \pm 5788.44
HF..ms.2..AR.	1832.8 \pm 4854.39	2127.52 \pm 6849.23	2081.95 \pm 6216.63
VLF..log..FFT.	3.85 \pm 1.33	3.55 \pm 1.08	3.45 \pm 1.19
VLF..log..AR.	4.32 \pm 1.25	4.12 \pm 1.15	4.05 \pm 1.51
LF..log..FFT.	5.87 \pm 1.46	5.34 \pm 1.33	5.43 \pm 1.8
LF..log..AR.	5.86 \pm 1.42	5.38 \pm 1.37	5.35 \pm 1.78

HF..log..FFT.	5.66±2.03	5.54±1.95	5.34±2.28
HF..log..AR.	5.75±1.94	5.68±1.89	5.35±2.29
VLF.....FFT.	8.43±6.05	8.95±7.77	9.76±9.6
VLF.....AR.	10.98±6.32	11.8±7.61	12.54±8.14
LF.....FFT.	49.46±17.73 ^a	41.44±19.15	44.8±18.24
LF.....AR.	46.34±16.83 ^a	38.32±17.76	42.09±18.85
HF.....FFT.	41.97±21.09	49.37±23.49	45.24±23.01
HF.....AR.	42.51±20.55	49.67±22.42	45.15±23.11
LF..n.u...FFT.	54.84±21.17	46.71±23.04	51.04±22.56
LF..n.u...AR.	52.98±20.79	44.66±22.14	49.41±23.73
HF..n.u...FFT.	45±21.04	53.03±22.83	48.75±22.41
HF..n.u...AR.	46.83±20.64	55.1±21.98	50.36±23.54
To- tal.power..ms.2..FF T.	3556.71±9388.3 6	3200.18±11501.2 2	3302.96±9532.39
To- tal.power..ms.2..AR .	3118.77±7817.3 1	3335.13±11715.8 4	3611.36±10389.3 3
LF.HF.ratio.FFT.	2.1±2.44	1.54±1.95	2.32±4.42
LF.HF.ratio.AR.	1.72±1.61	1.38±1.81	2.3±4.35

Significant differences between PREOP and 1POP: ^a $P < 0.01$. Significant differences between PREOP and 2POP: ^b $P < 0.01$. Significant differences between PREOP and 3POP: ^c $P < 0.01$. Significant differences between 1POP and 2POP: ^d $P < 0.01$. Significant differences between 1POP and 3POP: ^e $P < 0.01$. Significant differences between 2POP and 3POP: ^f $P < 0.01$.